ROTHAMSTED RESEARCH

Report for 1949

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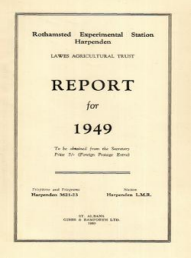

Departmental Reports

Rothamsted Research

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PHYSICS DEPARTMENT

By R. K. Schofield

Two vacancies, one caused by the appointment of Dr. B. A. Keen to the directorship of the East African Agriculture and Forestry Research Organization and the subsequent appointment of Dr. R. K. Schofield to the headship of the department, and the other caused by the appointment of Dr. E. W. Russell to the readership in soil science at Oxford, have been filled during the year. Dr. W. C. A. Hutchinson took up his appointment in September and has since been working with Dr. H. L. Penman in the field of agricultural meteorology. Mr. W. W. Emerson started in October to take up the general lines of work related to soil cultivation developed by Dr. Russell. Mr. A. W. Taylor also joined the department in October under a special grant from the Agricultural Research Council to work directly under Dr. Schofield in a study of the chemical potentials of ions in soil. At the beginning of the year Mr. P. C. Owen transferred to the Botany Department.

Dr. M. L. Puri completed his period as a voluntary worker and obtained the Ph.D. degree of London University. Mr. H. C. Aslyng continued as a British Council Scholar, and in December was appointed Reader in Soil Science at the Royal Veterinary and Agricultural College at Copenhagen.

Dr. Schofield has served on the Joint Committee on Soils appointed jointly by the Department of Scientific and Industrial Research and the Ministry of Supply. Dr. Schofield and Dr. Penman are both members of the Technical Panel of the Land Drainage Legislation Sub-Committee of the Ministry of Agriculture's Central Advisory Water Committee. Dr. Penman served on the Council of the Royal Meteorological Society and on the Board of the Institute of Physics. During July he visited Holland and lectured to the Hydrology Commission of the Dutch T.N.O. on Rothamsted researches on evaporation.

Soil Cultivation

Deep ploughing

The loss of Dr. Russell and the transfer of Mr. Owen, who had assisted him in the deep ploughing work, have restricted operations this year to the continuation of the six-course experiment at Rothamsted.

The plots which were deep ploughed this year have now been deep ploughed three times. The soil to plough depth is now well mixed, but there is little colour difference between the shallow and deep-ploughed plots. The only noticeable difference is the greater stickiness of the soil in the deep-ploughed plots.

As in previous years, the germination and growth of sugar beet was slower on the deep-ploughed plots, but the difference had disappeared by June. At harvest, the deep-ploughed plots yielded 9·2 tons per acre of clean beet, while the shallow ploughed plots yielded 8·6 tons per acre. Deep incorporation of phosphate gave an advantage of 0·9 tons per acre. A similar effect was found each year since 1944 except 1948. As before, deep incorporation of potash was without effect.

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Deep ploughing produced an increase in yield of potatoes from 5·7 to 6·7 tons per acre when potash was applied in the bouts. This can be accepted as a definite result for this site since it has occurred every year from the inception of the experiment in 1944 ; but no result of comparable consistency has yet been obtained at any outside centre.

The yield of wheat was again up by 1 cwt. per acre on the deep-ploughed plots. This advantage, though small, appears to be significant.

Agricultural Meteorology

General

In a discussion on meteorology in agriculture, organized by the Royal Meteorological Society, the department supplied an introductory survey showing the type of statistical, biological and physical problems demanding solution. An account of the 1948 irrigation experiment was given to illustrate the possibility of estimating crop transpiration from measurements of weather factors. The Agricultural Meteorology Branch of the Meteorological Office (M.O. 19) is showing an encouraging interest which will probably take a practcal form during 1950 when M.O. 19 hopes to issue monthly estimates of transpiration to the provincial centres of the National Agricultural Advisory Service.

Measurements of evaporation and drainage

Day to day measurements of evaporation from open water, bare soil and turf have been continued, and in the late summer apparatus was successfully designed to obtain continuous records. The records obtained for the open water surface generally show clearly the day maximum and the night minimum, but there are some anomalies, probably caused by differential thermal expansion of instrument components. The same apparatus, used to record the fluctuation of a water-table 2ft. below a turfed sandy soil, has given some details of the slow drainage referred to in 1948. Records show quite clearly that this drainage begins about sunrise and continues until nearly midday when the direction of movement of water is reversed as the effect of transpiration begins to dominate the flow.

Taking advantage of the dry summer, new copings have been fitted to the drain-gauges of Lawes and Gilbert, and slates on one wall of the 40-inch gauge have been renewed in the hope of stopping the leak discovered in 1940. Since the operation the drainage totals (November–December) have been :—20, 6·9 inches ; 40, 6·7 inches ; 60, 6·3 inches. The drainage from the 40-inch gauge is now less than that from the 20-inch gauge, as it should be, but is still not as close to that from the 60-inch gauge as might be expected.

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

Two centres were in use in 1949. On Mr. F. Secrett's farm at Milford there were four watering treatments :—unirrigated control (0), full irrigation at Mr. Secrett's discretion (F), and two restricted treatments (R and M) based on weather data collected on the site. Treatment R was designed to permit the building up of a water deficit of 1½ inches by the end of August, and was the same as in 1948 : treatment M was designed to permit an end-of-August

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deficit of 3 inches. On the farm of Messrs. W. O. and P. O. Jolly at Kesgrave, Ipswich, there were three treatments :—O and M as at Milford, and a third (J) determined by Mr. Jolly. The summer was very dry, the May to August rain being 4·4 inches at Milford and 4·7 inches at Kesgrave, and irrigation operations were frequent. At Milford, treatment F took 13·1 inches in nine applications, R took 8·4 inches in six, and M took 6·5 inches in five ; at Kesgrave, J took 4·1 inches in two, and M took 5·6 inches in four applications.

The summer was characterized by a severe attack of virus disease, low sugar percentages, and a curious interaction of watering and nitrogen treatments, of which there were four at Milford and three at Kesgrave. As the lowest and highest were common to both centres, values for these are given in the following table :—

Yield of sugar (*cwt. per acre*)

Treatment		O	M	R	F	O	J	M
Irrigation (I)	...	0	6·5	8·5	13	0	4	5·5
Rain + I. (in.)	...	4·5	11	13	17·5	4·5	8·5	10
Yield	0·4 cwt.N/a	36·0	44·3	44·2	44·1	30·2	49·8	53·6
	1·3 cwt.N/a	32·1	40·8	43·0	39·2	31·4	42·7	44·3

The results show the benefit of irrigation in a dry summer even for a deep-rooted crop like sugar beet. The benefit was greatest for the treatment based on weather data.

Rainfall, evaporation and run-off for the Stour Catchment

The Land Drainage Legislation Sub-committee of the Central Advisory Water Committee of the Ministry of Agriculture is gathering information through its technical Panel on the effects of land drainage on the flow of rivers. As a part of this inquiry Dr. Penman has examined the records of rainfall and run-off for the Stour Catchment over the period 1933 to 1948. On calculating the evaporation from mean values of meteorological observations taken at nearby stations he has accounted very satisfactorily for the difference between rainfall and run-off and for the changes in ground-water storage as exhibited by well records. Land drainage has been extensively carried out in this area since 1939 but it has been without discernible effect on the evaporation, and so cannot be said to have influenced the total amount of water discharged into the Stour.

Heat balance of the soil

Evaporation requires latent heat and this heat is a major item in the balance sheet of incoming and outgoing energy. The data for the Stour Catchment have been studied from this angle also. The results, which can be considered to apply to much of Southern England, show how incoming solar radiation is used up month by month throughout the year. Before and after the midsummer peak about half of the energy is used in evaporation (transpiration), and only small amounts are used in warming of the soil and the air. Throughout the year there is a fairly steady outward flow of long-wave radiation which, in winter, draws its energy from the soil and air.

In preparation for more detailed studies of heat flow in the soil, a set of resistance thermometers linked with automatic recording apparatus have been installed, which will measure the soil temperature down to 6 feet. It is hoped that the data thus accumulated will help to unravel the complex physics of radiation frosts.

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Micrometeorology

The thermistor bridge, described in 1948, has been greatly used by Dr. Broadbent to obtain records of temperature and humidity profiles, and of wind speed among potato crops of varied spacing over dry and wet soil.

Laboratory Work

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

It has been necessary to make further minor modifications in the method introduced by Russell for measuring the volumes of solids, water and air in soil clods. Using the original technique it is impossible to prevent evaporation of water from the clod during the series of manipulations, and it is difficult to estimate the errors this may cause. A redesign of the apparatus practically eliminates this source of error. Further tests will be carried out.

Vapour pressure of aqueous solutions

It has been difficult to decide which set of measurements to take as the standard for accurate evaluation of aqueous vapour pressures. Between 98 per cent. relative vapour pressure and saturation—the range of greatest significance in soil and plant studies—the values for solutions of NaCl and KCl should be obtained very accurately from measurements of the E.M.F. of concentration cells. Direct vapour pressure measurements have not yet been made with sufficient accuracy to serve as a check, but there are numerous published results giving the concentrations of isopiestic solutions with high precision. A comparison shows that either the E.M.F. values for NaCl or those for KCl must be less exact than their internal consistency would lead one to expect, and a search is being made for a criterion that will reveal which set of data is the more reliable.

Provisionally the E.M.F. measurements for NaCl are being used in preference to those for KCl, and tables have been drawn up relating the molality of NaCl solutions to vertical height in metres, which express the amount by which the potential of water in the solution is lower than that of pure water at the same temperature. These tables are being used in the study of environmental factors influencing seed germination which the Botany Department is carrying out with the co-operation of the Physics Department. Careful consideration has been given to the design of the temperature regulators of the double thermostat tank used for this work. The apparatus is very satisfactory in that no short period temperature fluctuation that would disturb the relative vapour pressure of the seeds' environment can be detected with a thermometer sensitive to 0·001°C.

Thickness of water films

An apparatus for the measurement of the thickness of water films on mica was set up and some preliminary work carried out. Following the Russian work, a hydrogen bubble is pressed against a mica plate immersed in a solution of an electrolyte. The thickness of the phase film over the area of " contact " of the bubble is estimated by comparison of its light transmission with that of the surrounding Newton ring system. The comparison can be made directly by means of a suitable light-sensitive cell mounted on a travelling microscope. Owing to the lack of a suitable microscope

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the method now being tried is a photographic one, which should at least have one advantage in giving a permanent record of each experiment. The necessary comparisons of the light intensities can be found by using a micro-photometer, and the bubble size by direct measurements on the photographic plate.

Thermodynamic potentials of soil constituents

Considerable progress has been made in the development of methods for determining the thermodynamic potentials of nutrients and other substances in soils. Where, as in soil, we are dealing with electrically charged particles it is difficult to define the potential of any single ionic constituent. We can ,however, define the difference of potential between electrically equivalent quantities of two cationic or of two anionic components, or the sum of the potentials of electrically equivalent quantities of two components, one cationic and the other anionic. Thus the pH of a soil suspension is not, in itself, a characteristic of the soil, inasmuch as it depends on the salt concentration, whether set up merely as a consequence of shaking up a soil sample in distilled water, or deliberately produced by the addition of $CaCl_2$. On the other hand, the difference of potential expressed by pH — $\frac{1}{2}$pCa has a definite value for a soil sample independent of salt concentration up to about N/50. We expect this principle to apply to any pair of cations, and one of the tasks ahead is to demonstrate this.

Particular attention has been paid to phosphate, and it has been found that the potential sum represented by $\frac{1}{2}$pCa + pH_2PO_4 is independent of $CaCl_2$ concentration up to 0·01 molar. Values so far obtained range from 5·5 for soils liberally dressed with superphosphate to 8·5 for soils on which all crops fail unless phosphate is applied. Fortunately these potentials can be rapidly determined, and it is hoped that they will provide a surer basis for advice on phosphate manuring than any of the conventional methods hitherto employed.

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CHEMISTRY DEPARTMENT

By E. M. Crowther

Fertilizer Experiments

Much of the work of the department is concerned with the analysis of problems of soil fertility and manuring by combining investigations in the laboratory, pot culture house and field experiments. Manurial experiments on sugar beet have been conducted in collaboration with the agriculturists of the sugar beet factories at some twenty centres each year since 1933, and the responses to fertilizers have been compared with those of laboratory examinations of soil samples taken before the fertilizers were applied to the plots. In many of the years leaf and root samples have been examined at the end of the growing season. This series of field experiments and an additional one on alternative forms of nitrogen fertilizers were continued in 1949. Arrangements for future experiments on this crop are under review.

In a much smaller series of experiments in co-operation with the staff of the Home Grown Threshed Peas Joint Committee and the National Agricultural Advisory Service from 1946 to 1949, the average responses to nitrogen and phosphate fertilizers were trivial and those to potassium fertilizer were profitable only on soils deficient in readily soluble potassium. Thus, grouping the experimental centres by soil analyses made by a rapid method in which the soil was extracted for one minute with 0·3 N.HCl the average responses to potassium fertilizer were :

	Readily soluble potassium in soil mg. K_2O%	No. of experiments	cwt. additional peas per acre from 2 cwt. muriate of potash per acre
Low ...	0–6	7	2·1
Medium	7–8	5	0·3
High ...	Over 8	13	–0·1

In these experiments the fertilizers were applied broadcast shortly before sowing. With this method of application there is little justification for manuring peas, except where acute potassium deficiency is suspected. It will be shown in a later section of this report that suitably placed fertilizers may give good responses where broadcast fertilizers fail.

For many years manurial experiments designed and analysed at Rothamsted have been carried out on tropical plantation crops. In one series started on newly budded rubber in Malaya in 1934 and supervised by Dr. W. B. Haines, growth in girth showed marked and very rapid responses to ammonium sulphate and mineral phosphate but not to sulphate of potash. The trees with nitrogen and phosphate were ready for tapping many months before the untreated trees. In 1948 and 1949 it was possible to remeasure the girths of the trees and to obtain several rounds of sample-tappings from two of the experiments, which had, of course, had no further treatment or attention after 1940. In one experiment the number of tappable trees was least on plots which had received no nitrogen or phosphate from 1934 ; there was a significant increase in the yield of latex from the earlier nitrogen dressings on plots which had also

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received phosphate. In another experiment on a different estate the numbers of tappable trees and the yields of latex per tree tapped were higher on plots which had received mineral phosphate from 1934 to 1940. These reults provide an interesting example of the way in which suitable manuring in the early stages of the growth of trees may show improvements over long periods.

In experiments on both mature and newly planted oil palm started in 1940 in two estates in Nigeria and one in the Belgian Congo, the effects of nitrogen, phosphate and potassium fertilizers were small and irregular in the early years, partly because it was not possible to maintain regular manurial dressings during the war. Progressive changes with time showed, however, moderate improvements from potassium fertilizer in several experiments and small improvements from nitrogen. In most of the experiments, including those started at the time of planting, there were negligible effects from phosphate fertilizers. Significant improvements in yield from phosphate were obtained only on a single kind of soil at one of the three estates.

Since 1945 several members of the department have co-operated with the Research Division of the Forestry Commission in investigations on nutrition problems in forest nurseries. A general summary of the principal findings is given in a separate section of this Report.

Phosphate fertilizers

It is well known that superphosphate may have relatively small residual effects on certain kinds of soil, especially very acid ones, and it is often assumed that other kinds of phosphate fertilizer are therefore to be preferred on these soils. Although we have not yet been able to make long-term experiments to measure the residual value of different kinds of phosphate fertilizers on acid soils, we have had a number of experiments in which superphosphate has given excellent results on acid soils in the year of application. Of the alternative kinds of fertilizer tested only silicophosphate has given higher yields and phosphate recoveries than superphosphate, and the superiority was very small. Very good results have been obtained from superphosphate in forest nurseries and forests, even on acid soils, and sometimes the advantage from superphosphate has been outstanding in comparison with Bessemer basic slag and ground mineral phosphate. These results are consistent with the view that a special merit of water-soluble phosphate applied at or shortly before sowing is to stimulate early root growth and establishment, which may be of the greatest importance in dry springs. This feature of soluble phosphate fertilizers can be fully exploited where safe methods can be found for placing the fertilizer close to the seed. It may then become possible to rely on moderate annual applications instead of attempting to build up large reserves in the soil. There are other conditions in which it may be desirable to maintain a continued supply of available phosphate over longer periods. Some possible methods are being tested. Newly planted forest trees have received compound fertilizer (5%N, 10% P_2O_5, 5% K_2O) compressed into one-ounce pellets, one on each side of the tree. Somewhat unexpectedly it was found that during the drought of 1949 over 90 per cent of the nitrogen, phosphorus and potassium had diffused out of the pellets after a few months. The pellets appeared unchanged but they

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retained little but gypsum. Although these observations suggest that the pellets may not act slowly enough for the purpose intended, the rapid outward diffusion of the soluble salts may reassure farmers who doubt the activity of granular fertilizers when they find apparently unaltered granules at the end of a season. To slow down the rate of action of phosphate granules or pellets it may be necessary to select relatively insoluble ingredients. Another method under test is to mix superphosphate with bulky organic materials, such as chaffed green bracken, with the object of producing a less soluble calcium phosphate within the pieces of organic matter. Such material might remain accessible to plant roots but be brought only slowly into contact with the soil.

Long-term residual effects of superphosphate and farmyard manure

An account is given in the Field Experiments section of this Report of the striking residual effects shown in the Hoos Field Exhaustion Land in the barley crop of 1949. Plots which had received either superphosphate or farmyard manure for many years before 1901 but none since gave fair barley crops whilst those which had received no phosphate in the wheat and potato experiments before 1901 showed most acute symptoms of phosphate deficiency. Plant samples taken on 14th May 1949 gave the following yields and analyses.

Treatment before 1901	Dry matter cwt. per acre	P_2O_5% of dry matter	P_2O_5 in crop cwts. per acre
No phosphate ...	1·1	0·32	0·004
Superphosphate ...	3·4	0·48	0·016
Farmyard manure ...	5·4	0·57	0·031

The fact that the phosphoric acid percentage increased regularly with the yield suggested that available phosphate was the principal controlling factor. The extra phosphate content on the better plots with manurial residues amounted, however, only to from 1 to 3 lb. P_2O_5 per acre. Analyses for readily soluble soil phosphate showed differences over a tenfold range. The yields of barley followed the soil analyses quite well, except that plots without potassium before 1901 gave poorer plants for a given level of soil phosphate than those with either farmyard manure or potassium sulphate before 1901. This shows a residual benefit from potassium fertilizer. Samples taken on the same day from the permanent barley plots in the same field gave about 0·6% P_2O_5 in the dry matter for plots without superphosphate and from 0·8 to 1·0% P_2O_5 in the dry matter from plots with superphosphate every year. Another experiment in the same field shows that the residual effect of superphosphate in this slightly calcareous soil falls off only very slowly from the second to the fifth year after application. The observations on the exhaustion land show that a small fraction of added phosphate and potassium may remain available for many years.

Rate of action of nitrogenous fertilisers

Crop residues, farmyard manure and composts may liberate available nitrogen over many months, whilst most nitrogen fertilizers, including such organic materials as dried blood and crushed hoof, act very rapidly. This may allow serious losses of nitrate by leaching, and in very acid soils even ammonium may be lost. For many crops growth might be steadier and manurial practice

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simplified if slowly acting nitrogen fertilizers could be prepared. Among the waste products we have tested the best results have been obtained from a plastic waste derived from formalized casein. Even slower and more prolonged action has been obtained in pots from crushed hoof which was inactivated by treatment with formaldehyde. A number of synthetic products, including several batches of urea-formaldehyde condensation products, have been tested. The rates of action have been assessed from pot experiments on repeatedly cut perennial ryegrass, the effects of dressings incorporated in the soil at the beginning of the experiment being compared with graded dressings of urea applied as top-dressings in factorial combinations on three occasions. In this way it is possible to assess the amount of available nitrogen supplied at different stages in the growth of the crop and to reduce the disturbance from the delayed response of the crop to nitrogen absorbed at an earlier stage. The absolute amounts of slowly available nitrogen obtained from any of the forms tested was small by comparison with the amounts of rapidly available nitrogen. No material tested gave results comparable with the same total amount of nitrogen applied in repeated dressings of a soluble form. For a given amount of early growth the amount of late growth increased in the order: urea, hoof, urea-formaldehyde products, formalized casein, formalized hoof. The results confirmed American findings that for urea-formaldehyde products both the early and the late supplies of available nitrogen increased with a conventional estimate of the "soluble nitrogen" in the product. It appears that much more experimental work will be required on the production and testing of ureaformaldehyde products before commercially useful materials can be prepared.

Fertilizer placement

Experiments comparing fertilizer placed near the seed with that broadcast were carried out in 1948 on sugar beet, mangolds and threshed peas. Two methods of broadcasting fertilizer were tested. Early dressings applied after ploughing were worked deeply into the soil by the cultivations given in preparing the seedbed. Late dressings were applied to the seedbed and were harrowed in shallowly. Fertilizer was placed three inches below the soil surface in bands at one inch and at three inches to the side of the seed.

Heavy dressings placed one inch to the side of the seed damaged the germination of sugar beet, mangolds and peas; bands three inches to the side of the seed were safe. Complete dressings of fertilizer for row crops should be placed not less than two inches to the side of the seed.

National Compound Fertilizer No. 2 (9%N, 7·5% P_2O_5, 4·5% K_2O) gave similar yields of sugar beet and mangolds when broadcast and when placed in bands at safe distances to the side of the seed. For such crops grown on average soils there is no advantage from placing fertilizer beside the seed except that the labour involved in applying the fertilizer separately is saved. Further experiments in 1949 have compared a phosphate-potash fertilizer (15% P_2O_5, 13% K_2O) broadcast and placed in a band two inches to the side of the seed. Preliminary results show that placed and broadcast fertilizer have again given similar yields.

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Phosphate-potash fertilizer (10% P_2O_5, 20% K_2O) was applied in experiments on threshed peas in 1948. Bands placed at the side of the seed gave consistently higher yields than the same quantity of fertilizer broadcast. Early dressings worked deeply into the soil gave slightly higher yields than dressings broadcast on the seedbed. In 1949 a phosphate-potash fertilizer (15% P_2O_5, 13% K_2O) applied three inches below the soil surface and two inches to the side of the seed gave consistently higher yields than the same quantity of broadcast fertilizer. The average *extra* yields of threshed peas from placing as compared with broadcasting 4·5 cwt. of fertilizer per acre in experiments over three years were

		extra yield of peas cwt. per acre
1947	3 experiments	2·8
1948	5 experiments	2·2
1949	6 experiments	1·5

One experiment in 1949 on peas picked green for canning gave higher yields from placing than from broadcasting fertilizer. Placement was also superior to broadcasting in three experiments on spring beans.

Radioactive Tracers

During 1949 apparatus was assembled and standardized for using radiotracers in soil and fertilizer investigations. Work elsewhere on the uptake of nutrients from soils and added fertilizers had revealed some uncertainties in the interpretation of results of experiments with radiotracers as indicators through possible damage to plants by radiation and also through isotopic exchange between soil phosphate and added phosphate. It was therefore decided to begin by examining isotopic exchange phenomena in simpler systems before proceeding to experiments on soils and plants. With anion exchange resins and preparations of basic calcium phosphate exchange with added phosphate proceeded very rapidly, equilibria being attained within a day or so. With coarsely crystalline fluorapatite the exchange, though much slower, was still appreciable. Estimates of the apparent surface for exchange were about ten times that calculated from the size of the crystals. Measurements of the speed and extent of isotopic exchange distinguish sharply between coarsely and finely crystallized materials, and thus offer means for comparing the surface activities of preparations of calcium phosphates and other materials likely to be involved in the behaviour of fertilizer products in soils.

Soil Organic Matter

Earlier work on the extraction of organic matter from soils and the nature of the organic nitrogen in soils was prepared for publication. It had been shown that at least one-third of the organic nitrogen of soils was in the form of protein. The amino-acid composition of soil hydrolysates has been studied by the paper chromatography technique and the following amino-acids identified; aspartic and glutamic acids, serine, threonine, glycine, alanine, valine, leucine, isoleucine, proline, hydroxproline, arginine, histidine, lysine, phenylalanine, tyrosine, β-alanine, α-amino-n-butyric acid and γ-aminobutyric acid. In addition, glucosamine and an

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unidentified substance giving a purple colour with ninhydrin have been detected. Preliminary investigations suggest that the latter is αε-diaminopimelic acid. Results so far obtained indicate that the amino-acid composition of the protein material in different soils is substantially the same. No free amino-acids have been detected in any of the soils studied.

The paper chromatography technique has also been employed in preliminary work on the nitrogen metabolism of soil and in a comparison of the amino-acid composition of fresh and rotted straws.

Manganese and Copper in Soils

In pot experiments on a fen soil low in total manganese the addition of small amounts of molybdate to the soil gave a considerable proportion of peas showing "Marsh Spot" under conditions in which untreated soil gave healthy peas. In a later experiment on a mineral soil low in total manganese healthy peas were obtained whether or not molybdate was added. It is possible that the effect of molybdate on the fen soil involved an increase in the ratio of soluble nitrogen to manganese in the plant, as earlier experiments had shown that "Marsh Spot" could be made more severe by injecting simple nitrogen compounds into plants. In pot experiments copper and manganese added on the surface of fen soils were held almost completely in the top centimetre or so of the soil. These results illustrate the firmness with which copper and manganese are retained in organic soils.

Neutral pyrophosphate extracts of organic soils when diluted with additional neutral pyrophosphate dissolve relatively large quantities of manganese when treated with manganese dioxide. In one case the neutral pyrophosphate extract corresponding to 1 g. of a fen soil dissolved 0·1 g. of manganese.

Soil Reaction

In an experiment on different amounts of chalk on a very acid light sandy soil at Tunstall, East Sussex, quite small dressings (1 ton $CaCO_3$ per acre) sufficed to give good crops of sugar beet so long as the nitrogen dressings were in the form of sodium nitrate. From 1941 onwards the sodium nitrate was replaced by ammonium sulphate and the yields of sugar beet and the pH values of the surface soils rapidly fell. Over the whole period of the experiment good yields were obtained on plots with surface pH values of 5·5 and over. In the early years the sugar beet failed when the surface soil had pH values around 5·0 but towards the end of the experiment there were moderate crops on plots with these very low pH values. The difference is due to the circumstances that in the early years the pH values of subsoils were low but in the later years the subsoils on the limed plots had relatively high pH values and exchangeable calcium contents through the leaching of calcium from the added chalk.

For some purposes, *e.g.* for growing lime-sensitive crops or for increasing the availability of certain micronutrients, it may be necessary to acidify field soils. A number of experiments have been made with such materials as sulphuric acid, aluminium sulphate, sulphur and ammonium sulphate. For the first year or so after treatment there is a risk of damage to certain sensitive species from the residues of some of these materials, especially in dry seasons.

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Experiments are in progress to discover what interval must be allowed for safety under various conditions.

GENERAL

Papers and reports dealing with the results of field experiments on crop rotations and manuring were prepared for two international conferences and for other discussions on fertilizer policy.

ANALYTICAL

A large amount of time was devoted during the year to transferring the vast collection of samples of soils and crops built up over a century from the old sample house near the laboratory to a new one in the outbuildings to the Rothamsted Manor.

As the first crops were cut in the new arable-ley rotation experiments at Rothamsted much time was devoted to devising satisfactory methods for handling and analysing the samples. Complications frequently arise in newly established leys and under some conditions in old permanent grass through the inclusion of appreciable quantities of soil in samples cut by a rotary scythe.

For periodic analyses of field and pot soils satisfactory results were obtained by rapid methods of analysis for nitrate by a brucine colorimetric test and for ammonia by nesslerising the ammonia collected in a Conway diffusion unit.

In the colorimetric determination of phosphorus by the stannous chloride-ammonium molybdate method, the solution containing phosphorus as orthophosphate must be free from iron. The tedious separation of iron by precipitating and filtering may be avoided by using Zeokarb 216, a cation exchange resin. Ferric iron is retained by the exchange material whilst the phosphate passes through completely and may be determined colorimetrically in the leachate without further treatment.

Low results in the micro-determination of fluorine by titrating with thorium nitrate may be caused by some of the fluorine being present as fluosilicate ion, SiF_6, after separation of fluorine from interfering ions by distillation from sulphuric or perchloric acid. The fluosilicate ion does not form an unionized compound with thorium as fluoride does. It was found that this error could be avoided by carrying out the titration in a 50 per cent. alcoholic system buffered at pH 5·3 using gallocyanine indicator.

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PEDOLOGY DEPARTMENT

By A. Muir

Weathering of Rocks and Minerals

During the year work was continued on the rocks and soils of the Malvern Hills. In the case of the soil derived from biotitite it has been shown that the clay mineral present represents a mixed chlorite-vermiculite structure. This is the first report of such a mineral type forming an essential part of the colloid fraction of a soil, although the existence of such a structure had been suggested, and later verified for larger crystals by Barshad in California. In the Malvern soil (of low pH) the predominantly chloritic material of the weathered rock passes into a vericulitic material in the soil, the transition taking place both in the coarse flakes of weathered biotite and in the clay, although the process does not seem to be quite the same for the two types of material. An interesting point is that even in the upper soil horizon there was very little true vermiculite present, most of it existing in mixed-layer minerals. On the basis of these observations it is suggested that there is a complete range of intermediate minerals between chlorite and vermiculite and an explanation of the possible means of transition can be given.

Clay Mineral Studies

A start has been made in a survey of the clay mineralogy of a large number of sedimentary rocks from various parts of England and Wales. In particular, several samples of Keuper Marl deposits have been examined, and the general presence of the chloritic components mentioned in last year's report has been confirmed. (See abstracts under Stephen and MacEwan, 1950). Analyses have also been made of soil clays from the Middle East and East Africa.

In connection with the expansion of X-ray diffraction work in the department, an experimental design for a gas X-ray set suitable for mineralogical work has been evolved and this is now being constructed.

Work on surface and interlamellar absorption by clay minerals and related substances, from solution, has been commenced by Mr. R. Greene-Kelly under a special A.R.C. grant.

Absorption complexes of α-zinc hydroxide

In extending the work on this subject it has been found that replacement of absorbed Naphthol Yellow anions can be effected by inorganic and aromatic anions. The kinetics of such exchange is specific for each anion. For halide anions, the rate of replacement follows the series $F^- > Cl^- >> Br^-$. The rate of replacement with I– is imperceptible (if there is any) even at elevated temperatures (70°C). Only the chloride exchange experiment resulted in the conversion of the primary dye complex into a flake of structure similar to the α–form of $Zn(OH)_2$ from $ZnCl_2$ solutions.

Anion exchange with *other* dyestuffs proved of greater interest. Three dyestuffs, of which two could not be induced to form primary complexes with α–$Zn(OH)_2$ due to low solubility or high molecular weight, were interacted with a flake of the primary complex. In all cases, the change in the basal spacings was consistent with a replace-

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ment of naphthol yellow anions; in two cases the observed spacings could be quantitatively predicted from a calculation of the areas of the dyestuffs molecules. This is, so far, the only proof (indirect as it is) of the uptake of dyestuff in layers. All attempts to induce preferred orientation in the primary naphthol yellow complex (including pressure treatment of some hundred atmospheres) were unsuccessful, and direct proof of layer absorption of dyestuffs by X-ray methods could not be obtained.

The conditions necessary for the production of the expanding type of the naphthol yellow primary complex mentioned in the Annual Report for 1948 were investigated; dyestuff concentration during precipitation and the extent of washing were found to be the critical factors.

Subsequently, a host of complexes has been prepared with different organic anions with a view to ascertaining what particular structural characteristics in the absorbed organic anions encourage the formation of stable well-oriented primary complexes. The occurrence of substituent nitro- or nitroso- groups, preferably in ortho- or para- configuration with -OH groups, seems to be conducive to their formation, suggesting a modified chelate bonding on the zinc hydroxide surfaces. Highly oriented and crystalline precipitates can be formed in this way, the effect being heightened by precipitation at higher temperatures. The temperature effect is less marked on complexes with larger organic anions or molecules containing a greater number of NO_2 groups.

Analyses of X-ray powder diagrams and uni-dimensional Fourier analyses of (001) reflections in oriented flake diagrams of some of these complexes reveals the uptake of the organic anions in layers. The Fourier analyses suggest the formation of $Zn(OH)_2$ layers with three sheets of (OH) groups in each layer rather than two as in the brucite structure.

Location of adsorbed ions and molecules on montmorillonite

This work has now been completed, and the resultant Fourier curves show two interesting points. Firstly, the exchangeable cations in the montmorillonite-glycerol complex take up a position midway between the inorganic layers of the mineral. Secondly, the structure of the inorganic layers of montmorillonite is in accordance with that proposed by Hofmann rather than that suggested by Edelman.

A similar study is now being made with hectorite, a trioctahedral montmorillonoid. This is not yet complete, but the Fourier curves confirm the Hofmann structure for the montmorillonoids.

Interstratified clay minerals

Work in the department and elsewhere has shown that randomly interstratified clay minerals are fairly common in soil clays. To facilitate their identification the intensity and distribution of scattered X-radiation from a number of types has been calculated using the formula derived by Hendricks and Teller (J. Chem. Phys., 1942, **10**, 147). The types chosen were those most likely to be encountered in practice and the results will prove of great value.

SPECTROGRAPHIC WORK

Work has begun on the investigation of the Mo content of soils, and working curves for its determination have been derived. It is

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already well known that certain soils derived from the lower Lias have abnormally high Mo contents and it is hoped that some information will be obtained on the general distribution of Mo in different types of soil. The Mo content of most soils appears to be of the order of a few parts per million only, which is near the spectroscopic limit of detection.

Some analyses for Mo have been done for the Botany Department on samples of lettuce from water culture experiments.

The routine analysis by the Lundegardh method has been going satisfactorily. Some 400 samples, mainly soils sent in by the soil surveyors, have been analysed for the exchangeable ions, K, Na, Ca, Mg, Sr and Mn. Some determinations of Mn have also been carried out on wild oat samples for the Botany Department.

Gleying in Soils

The study of artificially produced gleying on incubating soil material in sugar media has been continued. Determinations have been made of the residual sugar and ferrous iron contents of the fermentation solutions, as measures of the rate of microbial growth and of the gleying reaction respectively. In such experiments not only the sugar, but also the iron curves, are of sigmoid form, suggesting a microbial process as the rate-determining factor in the process of gleying.

Experiments have been made using grass or leaves in place of dextrose as the source of energy, thereby simulating soil conditions more closely. It has been found that under these conditions the results are comparable with those obtained in sugar fermentations, both in the extent and rapidity of the process.

The aliphatic acids produced in the sugar fermentations form complexes with ferric iron. As the published data on the composition of these complexes do not agree in certain instances, a number of redeterminations have been attempted by potentiometric and conductrimetric titrations—the methods used in general, by previous investigators. As a solution of a ferric salt is strongly hydrolyzed and consequently highly acid, it has generally been found necessary to employ solutions of the sodium salts of the organic acids in order to obtain a pH value sufficiently high to allow complex formation to occur. Thus during titration, the pH varies between wide limits, often by as much as 4 or 5 units. In addition to the direct effect of the pH on the quantity being measured, the relationship between the pH and the stability of the particular complex must be considered. Thus if during the titration of the sodium salt with a ferric solution, the pH falls to a value at which appreciable dissociation of the complex commences, the concentration of Fë˙ in the solution will increase, regardless of any consideration of the stoichiometric end-point of the complex formation. Hence the ratio Fë˙/organic acid, as determined by the point of inflection in the experimental titration curve, will be a function of the initial pH of the solution titrated, the pH of the titrant, and the dissociation of the complex as a function of pH, as well as of the theoretical composition of the complex. Should the complex be stable at low pH values, only the last factor will be operative. This is the probable explanation for the agreement of different workers on some systems,

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while the preceding factors, no doubt, are the cause of the non-accordance of results for other, less stable systems.

Bio-geochemistry of Aluminium

Aluminium accumulators were found to be far more widespread than was hitherto known. Vast areas of tropical rain-forests and secondary growth contain a large proportion—often pure stands—of Al-accumulating trees and shrubs. The effect of a continuous fall of leaves rich in aluminium on tropical soil formation is being studied. A preliminary analysis of 40 leaf samples from the Caucasus which were supposed to be aluminium rich did not reveal abnormal amounts of this element. Only a small part of the comparatively high total of the aluminium content of topsoils in this region can therefore be ascribed to present-day vegetation.

Since the tea-bush is the best known aluminium plant it was chosen for detailed study. From the analyses of over 300 samples from Ceylon and East Africa, the following points have emerged :—

1. The Al content is very low in the growing parts but increases continuously with age, rising to more than 17,000 p.p.m. from less than 100 p.p.m.
2. Phosphorus uptake is normal in a healthy tea-bush and its mobility is unaffected by the aluminium.
3. The tea-bush probably holds the record for high Mn content without toxicity symptoms ; healthy leaves may contain as much as 10,000 p.p,m. Mn. It is conceivable that the presence of similar amounts of Al protect the leaf tissue from Mn damage which would certainly occur in plants which are not aluminium-accumulators.

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SOIL MICROBIOLOGY DEPARTMENT

By H. G. THORNTON

WORK ON THE SOIL MICROPOPULATION

Relation of microscope to plate counts of microorganisms in soil

The development of a statistically satisfactory method for counting bacterial cells in soil by microscope counts has raised an issue of fundamental importance to soil microbiology, owing to the finding that microscope counts give estimated numbers many times higher than plate counts, which suggests the possibility that only a small fraction of the soil's bacterial flora has been studied by platings and by isolations from plate colonies. The application of this microscope method to the estimation of fungal mycelium in soil provides the only existing method of assessing the quantity of fungal material present in soil as mycelium, so that here also a comparison of such estimates with plate counts becomes important.

With regard to bacteria it seemed desirable in the first instance to obtain data as to the ratios of microscope to plate counts from a wide range of soils and also from samples taken at intervals from differently manured plots. The help of the National Agricultural Advisory Service bacteriologists has been obtained in this survey from different soil types and the results which they are obtaining are being received and collated.

Counts of microorganisms from Broadbalk plots

As mentioned in the previous report, counts of various groups of microorganisms were made from samples taken from some of the Broadbalk plots during 1948. The objects of this survey were not only to compare microscope and plate counts but also to assess by present day methods the effects of organic and artificial manuring on the soil micropopulation.

The microscope counts of bacterial cells and actinomycete spores were significantly correlated with soil moisture and with numbers of actinomycete colonies appearing on plates, but not with bacterial colonies. On Plot 2 (F.Y.M.) the total length of fungal mycelium found by microscopic examination was significantly correlated with numbers of fungal colonies on plots.

Microscope counts of bacterial cells and actinomycete spores, and plate counts of bacterial and actinomycete colonies both gave higher numbers on Plot 2 (F.Y.M.) than those obtained from Plot 3 (unmanured) or Plot 7 (complete minerals and ammonium suplhate) which were about equal. Manurial treatment did not significantly affect the total lengths of mycelium found by microscopic examination, but both Plots 2 and 7 gave higher plate counts of fungi than did the unmanured Plot 3. The numbers of amoebæ found in Plots 2 and 7 were not significantly different but both were higher than those found in Plot 3.

This survey of Broadbalk plots was carried out by a team of workers (Dr. Janet Mollison, Dr. B. N. Singh, Mr. P. C. T. Jones and Mr. F. A. Skinner).

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Partial sterilization

A field experiment on the effect of partial sterilization in a nursery bed for Sitka Spruce was carried out at Ampthill, Bedfordshire, by the Chemistry Department during 1949. The Soil Microbiology Department made a study of the micropopulation of soil samples taken from certain of these plots at intervals throughout the season. The results are not yet complete but indicate striking and persistent changes following the partial sterilization. (Dr. Janet Mollison, Miss Lettice Crump, Dr. B. N. Singh and Mr. P. C. T. Jones have been engaged on this survey).

Antibiotic actinomycetes

The possibility of using microorganisms that produce antibiotic secretions to control root disease fungi is being studied by Mr. F. A. Skinner in the special case of actinomycetes antibiotic against the fungus *Fusarium*. When such actinomycetes are grown with the fungus on plates of washed agar and mineral salts alone growth occurs but there is usually little or no evidence of antibiotic action, such action is however induced by the addition of glucose even in quite low concentrations. Antibiotic activity in agar is markedly reduced by the addition of charcoal or bentonite to the agar but not by the addition of Kaolin.

Some actinomycetes that are antagonistic to *Fusarium* on agar have not been found to produce antibiotic secretions in liquid culture even when aerated.

In this work it has become important to be able to measure growth of both the fungus and the actinomycete mycelium in liquid culture. This can be done in the case of the fungus by microscope counts and measurements of fragmented mycelium, but such a method is unsuited to the finer actinomycete hyphæ. Similarly we need a method for the comparative estimate of actinomycete mycelium and spores in soil. The effect of shaking suspensions of mycelium with sand showed a relationship between time of shaking and numbers of colonies found on subsequent platings, whereas with a suspension of spores time of shaking did not affect the count.

Resin attacking organisms

In his work on the biological decomposition of resins tested for the making of temporary roads Mr. P. C. T. Jones isolated a number of bacteria and fungi that could attack resins. The characters of these organisms and their action on resins has been further studied with a view to publishing descriptions of them.

Nitrification

The importance of nitrification in soil makes it important to find out what organisms are important in carrying out this process in soil. In view of recent work on the biochemistry of nitrification in soil it is important to make fresh study of the physiology of Nitrosomonas and Nitrobacter to see whether their behaviour agrees with that postulated for the nitrifying flora of soil. By a modified process, Dr. Jane Meiklejohn obtained and has described a pure culture of Nitrosomonas and found that this oxidized ammonia as rapidly as did a crude culture containing the commonly occurring contaminants. This makes it unlikely that the latter act symbiotically with Nitrosomonas as has been suggested.

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Soil amoebæ

Excystation of amoebæ. Miss Lettice Crump has studied the conditions governing the hatching of amoebæ from cysts and has found that morphologically similar species differ markedly in that one species will excyst only in the presence of bacteria of a suitable type while with the other, excystation is independent of the bacterial environment. This difference in behaviour provides a further specific factor likely to affect the relative numbers of different amoebæ in soil.

Nuclear division of classification of amoebæ. It is important to the study of the soil micropopulation that different species of amoebæ should be capable of identification. The classification and identification of amoebæ is largely based on the type of nuclear division, and there is great confusion at present largely owing to the processes of mitosis being wrongly described, often from insufficient material. Dr. B. N. Singh has developed a method for cultivating small amoebæ on glass slides coated with agar, that enables large numbers of amoebæ, in all stages of nuclear division, to be obtained readily and in a form facilitating the making of stained preparations. Twelve strains of amoebæ have been examined by this method and the types of division found are much less diverse than was formerly supposed, falling into two main categories. This discovery together with the further use of the new technique should result in a great simplification in classification and ease in species identification.

Mycorrhiza

In her earlier work Dr. Janet Mollison studied the distribution of the mycorrhizal fungus *Rhizophagus* in clover and wheat and found it to be abundant in the roots of both crops. Attempts to isolate the fungus and to grow it in a variety of artificial media have so far been unsuccessful.

When a series of dilutions of a soil suspension were applied to sterilized sand in which clover was grown the fungus was found to be present at a 1/10 dilution but not at a 1/1000 dilution. With a suitable dilution it may thus be possible to obtain otherwise comparable cultures with and without the fungus by which its effect on the plant can be assessed.

STUDIES ON NODULE BACTERIA (RHIZOBIUM) AND LEGUME CROPS

Geographical distribution of strains of clover Rhizobium

In continuation of the survey of the distribution of strains of clover Rhizobium, effective and ineffective in fixing nitrogen, a considerable amount of strains isolated from clover samples collected from the North and from the South West of England were tested for effectivity by Dr. Janina Kleczkowska.

A seriological study made by Dr. Margaret Read of 100 isolates from each of 17 localities has shown that strains of clover Rhizobium tend to be highly localized in their distribution, so that no rapid spread of a new strain whether or natural origin or introduced, is likely to occur under field conditions.

Establishment of clover Rhizobium in an " inoculated " crop

The abundance in some localities of ineffective strains of clover Rhizobium, suggests the use of seed inoculation to replace these ineffective strains by an effective strain in the soil. Any attempt to

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introduce Rhizobium into the soil by inoculation will meet with competition for nodule formation from the native population of clover Rhizobium already present. Hence the first problem to be solved was how far a culture introduced by seed inoculation can be established in the nodules of the crop in face of this competition.

To find this out it was necessary to develop a method for recognizing a strain introduced by seed inoculation into field soil already containing many other strains of Rhizobium ,and thus for distinguishing nodules produced by the inoculum from those due to native strains. In earlier work (Kleczkowski and Thornton) it had been found that strains of clover Rhizobium fall into groups identifiable by antigen tests and that strains containing certain antigens are uncommon in British soils. If seed is inoculated with a strain containing an uncommon antigen and sown in the field, cultures isolated from the nodules later developed can be tested with suitable antisera and in this way it is possible to determine whether they are of the same strain used to inoculate the seed. By testing sufficient nodule isolates the percentage of nodules produced by the inoculum can be estimated. An extensive series of experiments were carried out in 1948 and 1949 by Dr. Margaret Read with the co-operation of the National Agricultural Advisory Service. These were conducted at 13 centres at four of which the trial was carried on for two seasons. Each experiment consisted of 16 plots, four replications sown with uninoculated seed and four with seed treated with each of three strains of nodule bacteria selected for ease of seological identification. Cultures were isolated from 20-25 nodules from each plot and tested with suitable antisera. From those tests the percentage of nodules due to the inocula were estimated. Great assistance was provided by bacteriologists of the National Agricultural Advisory Service not only in the field trials themselves but also in certain experiments in isolating cultures from the nodules. Without their generous help so extensive a series of trials involving the isolation and serological testing of 6,000 cultures could not have been carried out. The results of these trials showed that it is possible to establish a culture of Rhizobium in the crop, in competition with the native bacteria, but that different strains of Rhizobium differ greatly in their ability to become established in the field. The experiments thus point to a new principle applicable to seed inoculation practice, namely that, in the selection of a strain for seed inoculation, not only effectivity in fixing nitrogen, but also ability to compete with native strains in the soil has to be considered.

Legume inoculation

A number of inoculation trials with clover and beans have been and are being carried out in various districts by the National Agricultural Advisory Service using cultures supplied by us.

Local adaptation between clover and Rhizobium

Experiments have been made by Dr. P. S. Nutman and Dr. Margaret Read to see whether, on farms where local strains of red clover, have been developed, the clover and the indigenous nodule bacteria have become mutually adapted to give enhanced nitrogen fixation. Material was obtained from seven farms in Sweden and in experiments carried out in 1948 and 1949, bacteria obtained from each farm were tested for effectivity on the local clover strain

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from the same farm and from each of the other six farms. In both experiments a small but significant effect was found, bacterial strains tending to be more effective on their own local clover strain than on the others.

Appearance of ineffective mutants of clover Rhizobium in soil

It was found by Dr. P. S. Nutman in previous work that if a pure culture of the highly effective strain " A " was kept in sterilized sandy soil from Woburn for six months, a considerable percentage of ineffective mutants appeared. This raised the practically important question whether this phenomenon was of wide occurrence in different soils or with many effective strains of Rhizobium.

To test the first point, Strain " A " was stored in sterilized samples of a range of different soils for half a year, after which the soil cultures were plated, random colonies " picked" and the resulting cultures tested for effectivity on clover.

We have again receiued much help from bacteriologists of the National Agricultural Advisory Service in setting up soil cultures and in the subsequent plating and isolations from colonies. The work showed that ineffective mutants tended to appear in acid soils and that their appearance could usually be prevented by the addition of $CaCO_3$. But in some cases mutants did appear in neutral and limed soils, so that other factors must also contribute to the effect. To test the stability of different strains of Rhizobium on soil storage, ten effective strains were stored in Woburn soil for 2 years. At the end of this time only one of these was found to have produced ineffective mutants, but this strain produced a high percentage. Dr. Janina Kleczkowska has been in charge of this work.

The production of mutants resistant to bacteriophage

It seems possible that the effect of bacteriophage in causing the appearance of a variety of mutant forms of Rhizobium might be a factor inducing a change to ineffectivity in field soils . Dr. Janina Kleczkowska has studied 'phage resistant mutants developed in cultures exposed to 'phage action. A number of these regained susceptibility to 'phage quite soon but were more liable to develop resistant mutants on further treatment with 'phage, than was the untreated parent strain. Amongst resistant mutants new colony characters were frequent. These were usually stable in artificial culture but readily lost on plant passage. Some resistant mutants also differed from the parent strain in their effectivity in the host plant. Many of these produced from an originally effective strain were ineffective, but the reverse change was much more rare. Mutants showing a change in effectivity varied very much in stability a number were stable during laboratory culture and after plant passage, but one strain was so highly unstable that it proved impossible to separate the effective and ineffective forms both of which were found in every colony after replating and plant passage.

The mechanism of attack by bacteriophage

Rhizobium bacteriophage is exceptionally good material for studying the process of attack on the bacterium and this problem has a special interest from its analogy to the infection process in plant viruses. Drs. A. and Janina Kleczkowski have examined the question how many 'phage particles are needed to start an infection. The work is still in progress but results so far are consistent with the

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view that a single 'phage particle will suffice to produce infection of a liquid culture or to initiate a plaque.

The inhibitory effect of nodule and lateral root meristem on further nodule development

Dr. P. S. Nutnam has continued his earlier work on the effect on nodulation of excising nodules and lateral roots of clover. The excision of effective nodules increases the number of nodules subsequently formed but that of ineffective nodules does not do so. The excision of the meristem tips of effective nodules or of lateral roots also increases subsequent nodule numbers. These reults suggest that a substance inhibitory to nodule formation is produced in meristems. In ineffective nodules the meristem tip is ephemeral and persists for too short a time to produce an effect.

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BOTANY DEPARTMENT

By D. J. WATSON

P. C. Owen was transferred from the Physics Department to the Botany Department in January.

J. H. Wilson, of the Department of Agriculture, Tasmania, joined the department in January, as a temporary worker.

Miss G. N. Thorne was appointed in October to work on nutrient uptake from solutions sprayed on leaves.

MICRONUTRIENTS

The interaction of molybdenum and nitrogen supply has been studied in lettuce and red clover grown in solution culture. For the lettuce, nitrogen was supplied at three rates, in all combinations with three rates of molybdenum supply (0, 0·1 and 5 or 10 p.p.m. Mo). Samples were taken on three successive occasions for dry weight, nitrogen and molybdenum determinations. No benefit from added molybdenum was found after 3 weeks treatment ; the highest rate caused a slight reduction of dry weight and visible symptoms of toxicity in the leaves. After 5–6 weeks treatment, the dry weight of a spring variety of lettuce, Tom Thumb, increased with increase in molybdenum supply at the two higher rates of N supply, but not at the lowest rate, and the depression of dry weight by the highest rate of molybdenum supply had disappeared. The positive interaction between Mo and N persisted in the later stages and became greater. In a winter variety of lettuce, Cheshunt Early Giant, addition of molybdenum gave no increase in dry weight at any stage; the highest rate of Mo supply, 10 p.p.m., caused a reduction of dry weight especially at the higher levels of N supply.

The total N content percent of dry matter was reduced by addition of Mo. In the plants without Mo there was some evidence of nitrate accumulation, though NO_3-N never accounted for more than about 10 per cent. of total N. The results, therefore, do not wholly support the conclusion of Mulder and others that Mo-deficiency inhibits nitrate reduction.

For the experiments on clover, three rates of nitrogen supply in combination with two rates of molybdenum (0 and 0·2 p.p.m. Mo) were used, in two different types of culture solution. In one experiment the plants were inoculated with *Rhizobium* and in another they were uninoculated. The nitrogen content of the culture solution used for the inoculated plants was reduced as growth proceeded, and in the later stages the plants were wholly dependent for their nitrogen supply on fixation by *Rhizobium*. The uninoculated plants grown without added Mo showed visual symptoms of Mo deficiency in the leaves, especially when the N supply was low, but at harvest after about 6 months growth, there was no detectable effect of Mo supply on dry weight or nitrogen content. The dry weight of the inoculated plants, harvested three months later, was increased by addition of Mo, and the number of nodules was depressed. This effect of Mo supply on nodule formation confirmed the results of previous experiments.

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Nutrient Uptake by Excised Root Systems

The object of this work is to establish quantitative relationships between the rate of uptake of nutrient ions by excised roots and the concentration of these ions in the roots and in the external solution. Barley and pea plants were grown for 6–7 weeks in culture solutions, with varied supply of nitrate, phosphate and potassium. The carbohydrate content of the roots was varied by shading some of the plants for several days before the roots were taken for experiment. The root systems were cut off and held at constant temperature in a flowing aerated nutrient solution of constant composition. Samples taken at the beginning and on succesive occasions throughout a 24 hour period, were analysed for N, P, K and carbohydrates. The rates of respiration of the roots was measured throughout the period. A series of six experiments of this type has been carried out.

The analyses are not yet completed, but there is evidence that the rates of uptake of nitrate, phosphate and potassium were all dependent on the carbohydrate content, as well as the nutrient content, of the roots. Roots from plants grown with similar nutrient supply at different times of the year varied in their capacity for ion absorption ; this was probably the result of seasonal variation in carbohydrate content. Simultaneous uptake of one ion and loss of another was observed. The losses of nutrients from excised roots took place into solutions of higher concentration than those in which the intact plants were grown ; uptake was found only when the concentration of the ion in question in the solution used for growing the plants was much below that in the solution in which the excised roots were held.

The adsorption of nitrate by low-N roots was accompanied by a rise in the rate of respiration. Absorption of phosphate by low-P roots or of potassium by low-K roots did not increase the respiration rate. Low-P and low-K roots behaved like roots with a high content of all three nutrients in showing a decline of respiration rate throughout the experimental period, possibly due to falling sugar content. The rise in respiration rate associated with nitrate absorption is thought to be a different phenomenon from the " salt respiration " observed when plant tissues are transferred from water to a salt solution. It may be a metabolic effect, associated with rapid conversion of nitrate into organic nitrogen compounds.

Similar experiments were made with barley and pea roots dug from small field plots. The dry season made it difficult to remove the root systems from the soil without serious damage and loss of the finer branches, but in more favourable weather conditions it should be possible to obtain satisfactory field material for nutrient absorption studies.

Uptake of Sugar and Mineral Nutrients by Leaves

An investigation has been started on the effect of spraying plants with solutions of sugar or mineral nutrients. American workers have reported that when tomato plants growing at high temperatures and in low light intensities (*i.e.* the conditions in a heated glasshouse in winter) were sprayed with sucrose solution, the rate of stem elongation and the dry weight of the plant was increased. This result was confirmed, but the effects on growth were not such as would be expected merely from an increased carbo-

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hydrate supply. For example, the increase in dry weight was restricted to the leaves, the part of the plant that would be least expected to suffer from carbohydrate deficiency, the dry weight of the stem was not affected although its length was increased, and the dry weight of roots was reduced. Further work on this is now in progress.

Work on the uptake of mineral nutrients by plants from solutions sprayed on the leaves was not begun until October. Its immediate object is to test a report that small amounts of potassium nitrate applied in overhead irrigation water to horticultural crops have a marked beneficial effect on growth and yield. Preliminary experiments were made to find out what concentration of nutrient salts can be used without scorching the leaves, and to determine whether appreciable amounts of nutrients can be absorbed from spray deposited on the leaves. In an experiment on young sugar beet plants, the amounts of N, P and K present in the leaves of plants sprayed daily for 6 weeks with a complete nutrient solution, was 15–40 per cent. higher than in the leaves of control plants sprayed with water. Experiments are now in progress comparing rates of uptake through the roots and through the leaves in different species. The rates of uptake of nitrogen from solutions containing equivalent concentrations of ammonium or nitrate are also being compared. Experiments to study the effects on growth of nutrients supplied through the leaves will be started in the spring when growing conditions are more favourable.

Water Relations of Germination

In collaboration with the Physcis Department, a study is being made of the dependence of germination of wheat seeds on moisture potential. The seeds are held close to the surface of a salt solution of accurately known vapour pressure, in a system kept at constant temperature ($\pm$ about 0·001°C), so that water is supplied to the seed through the vapour phase at a known moisture potential.

The first experiments, continued for 4–5 days, indicated that there was a sharply defined critical moisture potential below which seeds were unable to absorb enough water to germinate. Further work showed that the rate of germination was reduced by reducing moisture potential ; for example, at 20°C in an atmosphere saturated with water vapour, which we take as zero potential, wheat germinates in about 3 days, while at a moisture potential of –250 metres of water, it takes about 10 days. Seeds have been kept for 20 days at lower moisture potentials, and some have germinated in this time against a potential of –300 metres of water, *i.e.* a pF of nearly 4·5, considerably above the permanent wilting point (pF 4·2, equivalent to –150 metres of water). If there is a critical moisture potential below which germination cannot take place, it must be much lower than the first experiments suggested.

In the more prolonged experiments it has been found difficult to prevent fungal infection. Several methods of sterilizing the seeds have been tried, but none has been completely successful.

Biology of Wild Oats (*Avena fatua* and *A. ludoviciana*)

Work on wild oats was concerned with their growth and nutrition

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in comparison with cereal crops, and various aspects of the dormancy of the seeds.

Susceptibility to manganese deficiency

The susceptibility of wild oats to " grey speck " disease, caused by deficiency of manganese, was compared with that of two varieties of cultivated oat,—Scotch Potato, which is said to be relatively resistant, and Star. Plants were grown in pot culture in a manganese-deficient Fen soil, without added Mn, and with Mn added at three rates, the highest rate being fixed at a level estimated as adequate to correct the deficiency. *A. ludoviciana* showed the greatest response to Mn supply in total dry weight, shoot number and shoot height, and was the first to show chlorosis at the lower rates of Mn supply. The leaf symptoms of Mn deficiency in this species were different from the characteristic grey-speck lesions found in the cultivated oats and *A. fatua* ; they consisted of interveinal chlorotic stripes which later became necrotic. The effect of Mn supply on dry weight at harvest did not differ greatly in Star and Scotch Potato, but Mn deficiency caused more severe leaf symptoms and greater delay in ear production in Star. *A. fatua* was the least affected by varying Mn supply. Mn-deficient wild oats showed a smaller per cent. reduction of seed number, but a greater per cent reduction in weight per seed than cultivated oats.

Analysis of growth and response to nitrogen of wild and cultivated oats

One way in which weeds reduce crop yield is by competition with the crop for the supply of nutrients, especially nitrogen, in the soil. Pot experiments are in progress to test whether wild oats differ from cereal crops in their ability to take up nitrogen. An experiment comparing the two species of wild oat with barley at three levels of nitrogen supply has been completed, and a second one, comparing wild oats with cultivated winter oats and winter wheat was set up in November. Samples were taken at intervals for determination of nitrogen content, and the usual measurements required for growth analysis (dry matter, leaf area, shoot counts etc.) were made to see whether there are any attributes of growth other than nitrogen uptake that may give wild oats a competitive advantage.

Dormancy of the seeds

In a field experiment on potatoes on Rothamsted Farm, wild oat seedlings were found only in the ridges where dung was applied. This observation suggested either that the dung had contained viable wild oat seeds, or that it had broken the dormancy of seeds already present in the soil. To test these possibilities, samples of dung, unfortunately not from the same bulk as was used for the potato experiment, were brought to the laboratory, spread in pans with and without the admixture of sand, and kept watered to induce non-dormant viable seeds to germinate. Seeds of *A. fatua* or *A. ludoviciana* were added to similar pans of dung and equal numbers of seeds were sown in wild-oat-free soil. The added seeds have begun to germinate both in dung and soil, but so far no seedlings have appeared from the dung without added seeds.

Dormancy in *A. fatua* is apparently due to impermeability of the seed-coat to oxygen, for germination can be induced at any time by pricking the seed with a needle. Seeds of *A. ludoviciana*, however, cannot consistently be made to germinate by pricking, and evidently

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this species exhibits dormancy due to factors in the embryo or endosperm, as well as dormancy due to impermeability of the seed-coat. Some time has been spent in developing a technique for growing excised embryos of wild oats on nutrient agar, with the intention of using it to study the causes of dormancy of the embryo.

An anatomical and microchemical examination showed that the seed-coats of *A. fatua* and *A. ludoviciana* are very similar in structure.

Physiological Effects of Virus Infection

Seed-certification schemes for the control of virus diseases in potatoes depend on the recognition of infected plants in field crops by inspection. It is, therefore, important to know whether the presence, or the intensity, of visible leaf symptoms depends on the conditions of growth. A pot experiment was set up to determine the effect of varying nutrition and light intensity on the symptoms of leaf-roll infection. Small sets cut from healthy or infected tubers of Craig's Defiance, were grown with varied supply of N, P, and K with full daylight or under muslin shades which reduced the light intensity to about half that of full daylight. Some of the plants grown from healthy tubers were infected by means of aphids soon after the shoot appeared. It was found that high N supply and shading both tended to mask the leaf-rolling and yellowing symptoms. The same experiment provided material for a growth analysis study, the object of which was to determine the changes in growth caused by infection that lead to a reduction of yield, and to study the interaction of infection, nutrient supply and shading. Samples were taken at fortnightly intervals during the growth period for the measurement of dry matter in the different parts of the plant, and the total leaf area. Other attributes of growth including the number of leaves, lateral shoots and tubers and shoot height were also measured, and samples were kept for determination of nutrient content. The data obtained are now being analysed.

In collaboration with the Plant Pathology Department work on the effect of infection with yellow virus on the carbohydrate metabolism of sugar beet has been continued. This confirmed previous experiments in showing that the accumulation of starch and sugars in the leaves of infected plants is not attributable to an inhibition of translocation, as earlier workers thought.

Field Work

Samples of hay for botanical analysis were taken from twenty plots of the Park Grass experiment, selected because no analyses of the herbage on them had been made in recent years. When these analyses are completed, information on the present composition of the flora of all the plots will be brought up to date. Dr. Brenchley has continued to work on the revision of her book " The Manuring of Grassland for Hay," which describes the changes induced in the flora of these plots by long continued difference in manuring.

The usual routine observations were made on the weed flora of Broadbalk and Hoos fields.

A growth analysis study to compare the effects of nitrogenous fertilizer on spring sown wheat, barley and oats and to analyse the responses in yield, was carried out on small field plots. Samples were taken at fortnightly intervals from the end of April to early

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August for the determination of dry weight, leaf area and nitrogen content. An attempt was made to estimate the dry matter contributed by photosynthesis in the inflorescence of each species, by measuring the dry matter increment over short periods of plants from which the ears were removed, in comparison with intact plants. Nitrogen determinations on the samples, and the statistical analysis of the data, have not yet been completed.

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STATISTICS DEPARTMENT

By F. YATES

During 1949 the work of the department has developed along the lines which have been outlined in previous reports. Considerable progress has been made in our relations with the National Agricultural Advisory Service. Work on surveys of the operational research type has been intensified, and the year has seen the installation of Hollerith equipment.

The outstanding new survey carried out during the year is the Survey of Marginal Land. This was undertaken at the request of the Agricultural Research Council. The object of the survey was to investigate how far marginal land of the type not included in the Hill Farming Act, and not producing cash crops such as dairy products, was likely to repay any scheme of rehabilitation. The survey is being carried out in three regions ; that for East Wales and the Welsh Borders has already been completed and a preliminary report prepared.

The Survey of Maincrop Potatoes was continued, and the pilot survey of Methods of Milk Production was also continued, though a report has not yet been issued. Some analytical work on the Survey of Fertilizer Practice was carried out. A Survey of Opencast Coal Sites is being planned.

DESIGN AND ANALYSIS OF EXPERIMENTS

The design and analysis of experiments for Rothamsted and other research stations has continued on the usual lines. In addition to the design of field experiments a number of laboratory experiments have been designed for other departments. Similar work has been undertaken on request for other research stations.

The grazing experiment on the residual manurial value of feeding stuffs, which was being conducted at Rothamsted on behalf of the Royal Agricultural Society of England, came to an end in 1948 and members of the department corroborated in a report on this survey which has now been prepared for publication in the Society's journal (56).

Co-operation with the National Agricultural Advisory Service in the field of experimental design and analysis has made very satisfactory progress. We are now consulted by all the provinces, and Dr. Boyd or some other member of the department usually attends meetings of Provincial Experiments Committees in most provinces. Although this involves the department in a good deal of work it should produce valuable results both in raising the standard of design of individual experiments, and what is even more important, in providing a basis for the joint planning and co-ordination of experimental investigations. After a slow start there are now also welcome signs that the machinery set up by the Ministry of Agriculture to assist in this planning and co-ordination is beginning to function. It is hoped that during the coming year this headquarters organization will have an increasing influence both on the planning of co-operative experiments carried out by the National Agricultural Advisory Service on commercial farms and also on the planning of experiments on the Ministry's experimental husbandry farms.

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Various problems in the theory of the design of experiments have been investigated in the course of the year. Mr. F. J. Dudley, of the National Institute of Poultry Husbandry, and Mr. D. R. Read published a paper on the design of experiments in egg production of poultry (58). Dr. P. M. Grundy prepared a paper on the estimation of error in rectangular lattices (59), and Mr. M. J. R. Healy and Dr. Grundy have prepared a paper on the use of the principle of restricted randomization in quasi-Latin squares (60). The general basis of this principle, which is of fairly wide application, was discussed by Dr. Yates in two lectures on the logical basis of experimental design, and recent developments in the subject, given in Paris to the Institut Henri Poincaré in December, 1949 (69), (70). Dr. Yates contributed a paper on the place of experimental investigations in the planning of resource utilization to the Plenary Session of the United Nations Scientific Conference on the Conservation and Utilization of Resources (66), though he was unable to attend the Conference. He also gave a paper on experimental techniques which are of value in plant improvement to the meeting of the Biometric Society held in Geneva (68). Mr. Healy also attended this meeting. Mr. H. D. Patterson carried out some research into change-over trials such as are suitable for animal feeding trials, and has prepared a paper on this subject (64). He also prepared a thesis on which he was awarded the degree of M.Sc. at the University of Leeds (63). Mrs. P. M. Cox (Clarke) has written up an account of the analysis of $p \times q$ lattice designs (57).

Sampling Methods

Various members of the department have continued work in this field. Mr. D. R. Read published a paper on the accuracy of sampling methods for the estimation of egg production and mean egg weight (65). Dr. Yates attended the third meeting of the United Nations Sub-Committee on Statistical Sampling which was held in Geneva, and he and Mr. Healy attended the meeting of the International Statistical Institute held in Berne. At the latter Dr. Yates gave a paper on the use of sampling survey methods and operational research techniques in agriculture (67). Dr. Yates gave two papers on recent developments in sampling methods to the Institut de Statistique in Paris (71), (72). He also gave four lectures on sampling methods to the school (Centre Europeen) set up by the Food and Agriculture Organization of the United Nations for the training of official statisticians in the collection of population and agricultural statistics.

The book on sampling methods in censuses and surveys referred to in the 1948 report was published in May, 1949. From correspondence which has been received from Colonial workers and others and from personal discussions, it is clear that the book is fulfilling its purpose of providing a standard textbook whereby workers without extensive statistical training who are concerned with the conduct of sampling surveys can undertake them with confidence. A number of plans for sample censuses and surveys based on the methods explained in the book have been submitted to us for our opinion, and it is gratifying to find that the proposals have almost invariably been sound.

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Survey of Marginal Land

A survey of marginal land in England and Wales is being undertaken at the request of the Agricultural Research Council, with the object of investigating what improvement in production is possible from this type of land, and what expenditure would be necessary to attain it. The survey has been organized and carried out under the direction of Professor W. E. Ellison of the University College of Wales, Aberystwyth, and Dr. Boyd. Three areas have been selected for field survey: East Wales and the Welsh Border, Northern England, and South-Western England. The Welsh survey was begun at the end of September and a preliminary report was completed before the end of the year. Field work is in progress in the Northern and South-Western counties.

The boundaries of the surveyed regions have been chosen so as to include those areas in which the farms were not, in the main, producing cash crops, fat stock or milk, and which were not eligible for full benefits under the Hill Farming Act (1946).

The sampling procedure for the Welsh region was as follows. Within the region a stratified random sample of eight parishes or part parishes was selected for survey. Within these parishes or part parishes either all, or a random half of the farms of over 25 acres crops and grass were included in the survey, with the exception of farms that were receiving Hill-Sheep subsidy at the full rate, or of which more than 30 per cent. of the acreage consisted of land of good natural fertility. One hundred farms in all were included in the sample. Each of these was visited by a surveyor who recorded sales and purchases of crops and stock and made a field-by-field survey of the farm. This field survey involved a record, for the years 1948 and 1949, of the cropping, the yields or stock-carrying capacity (estimated or actual), and the manuring and liming. The surveyor also recorded what improvements he considered to be required in respect of cultivations, manuring, draining and fencing; their cost; and what yield or stock-carrying capacity could be expected from the field over a period of six years following the improvement. The surveyor was instructed to consider what improvements were desirable from the point of view of the farm as a unit, so that, for example, one field might be scheduled for arable production and another for direct reseeding, in the light of the probable needs of the farm as a whole and aiming as far as possible at self-sufficiency throughout the year. The extent to which improvements to buildings, roads and services were required was recorded by a special fieldman who visited about one third of all the surveyed farms.

Survey of Maincrop Potatoes

This survey, which was organized at the request of the Agricultural Improvement Council and begun in 1948 (73), (74), has been continued on the same lines in 1949. The field work has been carried out by officers of the National Agricultural Advisory Service.

The survey is intended 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. It is also designed so as to test the possibility of estimating the yield of the potato crop by

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digging up and weighing short lengths of row as near to lifting date as conveniently possible. In 1949 weights of sample lengths of row on some of the fields were also taken in August, in order to investigate the possibility of predicting the yields from measurements of this type.

In 1948, which was a particularly good year for potatoes, the sample yields gave results decidedly above the official estimates of the Ministry of Agriculture. The results for the mean of all the surveyed counties were as follows:

		tons per acre
Gross yield of samples (1¼ in. riddle)		10·8
Less		
Ware left in ground after harvest	0·8	
Correction for change of riddle (1¼ in.—1½ in.)	0·3	
Correction for headlands, etc. included in acreage	0·4	
Total		1·5
Estimated corrected yield of ware		9·3
Ministry of Agriculture's estimate		8·1
Difference		1·2

A similar comparison should be available in the near future for 1949, but at present we are awaiting the Ministry's estimate. The mean sample yield for 1949 over all the counties surveyed was about 2 tons per acre less than 1948 (75).

The corrections given in the above table for ware left in the ground after harvest and for differences in area were estimated by sampling methods. It will be seen that the amount of ware left in the ground after harvest, 0·8 tons per acre, is very considerable. A check on the accuracy of the sampling and of these corrections was obtained by comparison with farmers' weighed yields, where the latter were available. The mean excess of the gross sample yields was found to be 1·6 tons per acre, agreeing closely with the total correction of 1·5 tons given above. The sampling standard error from all causes was approximately 40 per cent. per field. About 1,600 fields were included in the survey, but allowing for variations in weighting the "effective" number was of the order of 1,000, giving a sampling error of about ±0·12 tons per acre.

Apart from yield estimates the most striking result that emerged from the 1948 survey results was the marked association between late planting and low yields. Indeed, the time of planting was the factor amongst all those recorded which produced the largest apparent effect on yield. In those parts of the country where early planting was common (in particular the south-west and the Fens) there is a general indication that March plantings yielded at least a ton more than those in the first half of April, although the later plantings show little further loss. Data for the south-eastern and southern counties and for the West Midlands suggest that time of planting had little effect on yield up to the middle of April, but that, for seed put in after this time, delayed plantings gave a substantial loss, amounting to about three quarters of a ton per acre per week. It is, of course, too early yet to say whether this effect

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is likely to occur in all seasons, but the result agrees with such few experiments as have been done on the effects of late planting. These experiments have indicated on the average a steady loss on the total yield of just over 0·5 tons for each week's delay up to the beginning of June. It is clear that further experimental work is required on this point.

The 1949 results are now under analysis, and the comparison between the results of the two seasons, which were meteorologically very different, should prove of considerable interest.

Colonial Work

The department has agreed to accommodate a statistician to be appointed by the Colonial Office. This statistician would be required to summarize the results of previous colonial experimental work, and assist in the Colonial advisory work undertaken by the department, particularly in the fields of experimental design and analysis, and sampling methods for censuses and surveys. A suitable candidate for this post was in fact found, but unfortunately through administrative delays the appointment fell through, and no other suitable candidate has yet offered himself.

We have had the usual volume of consultant work for the Colonies, in particular Mr. Church has continued his work for the West African Cacao Research Institute and has been invited to pay them a short visit. Four workers from the Colonies worked in the department for varying periods and we have had a large number of visitors from the Colonies.

Other Work

Many miscellaneous problems have been submitted to the department in the course of the year. In particular Mr. Dyke and Miss Poulton carried out an analysis of the results of a series of world-wide collaborative tests on the analysis of pyrethrum flowers (76). Mr. Dyke has continued to act as statistical adviser to the Advisory Entomologists. Mr. Healy has been giving assistance in the analysis of a series of anthropometric observations to the Department of Anatomy, Birmingham University. In addition, Mr. Healy prepared a paper on the routine computation of biological assays involving a quantitative response (61), and Mr. Jolly has evolved a method for the use of probits in combining percentage kills (62).

Hollerith Equipment

A Junior Rolling Total Tabulator was installed in June, 1949, as promised, and has been in active operation since then. It has already proved its value. As was expected, having a machine on the spot under the direct control of the research workers has resulted in a far more enterprising and flexible approach to punch-card work than was the case when all tabulations had to be carried out at a separate bureau. The choice of the Junior Tabulator has also proved a happy one, as this machine is sufficiently simple to be mastered by the research workers who require to use it in the course of their research, and at the same time is capable of a wide variety of operations, which are of use in research work. We are at the moment negotiating with the Company for some special modifications which will further increase the utility of the machine. In addition to its use in the analysis of survey work, we are exploring

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the possibilities of carrying out the analyses of the more complicated experiments on this machine—particularly those which involve a number of different measurements on which analyses of co-variance as well as variance are required. This type of analysis has proved to be too heavy for routine work on desk calculating machines, and consequently has tended to be neglected.

STAFF

The following appointments were made in the course of the year: Dr. P. M. Grundy (October, 1949. Previously working at Rothamsted as a Ministry of Agriculture scholar); Mrs. M. Hale; Mr. P. R. D. Avis (December, 1949) from Nottingham University.

The following members of the department left to take up appointments: Mrs. M. Hale (October, 1949) Spectrographic Department, Magnesium Electron Ltd.; Mrs. P. M. Cox (Clarke) (December, 1949) National Institute for Research in Dairying; Miss M. A. Creasy (October, 1949) to take up a Ministry of Agriculture Scholarship at Oxford University.

Ministry of Agriculture Scholars: Dr. P. M. Grundy (to October, 1949); D. H. Rees (October, 1949) from Imperial College, London University.

Workers from other Stations: Mr. C. P. Cox (National Institute for Research in Dairying, Shinfield) was accommodated in the department until December, 1949. Mrs. C. P. Cox also worked here from her appointment in November, 1949 until the end of the year. Mr. J. A. Nelder, who was appointed in October, 1949 as statistician to the newly set-up Vegetable Research Station, is working at Rothamsted until accommodation is ready for him at this Station. Eight temporary workers from other organizations, four of them from the Colonies, worked in the department for varying periods during the year:—

Name	*Location*	*Period*
British Isles		
P. N. Harvey	Norfolk Agricultural Station, Sprowston, Norwich	March 1949—April 1949
G. Carruthers	Royal Navy (afterwards to University of Cambridge)	May 1949—September 1949
R. M. Jones	University of Cambridge	May 1949—July 1949
Miss H. Wilton	Grassland Research Station, Drayton	November 1949
Gold Coast		
J. Quartey	West African Cacao Research Institute, Tafo	April 1949—April 1950
R. Wickens	West African Cacao Research Institute, Tafo	November 1949—March 1950
Nigeria		
A. N. C. Thomas	Department of Agriculture, Nigeria	September 1949—October 1949
East Africa		
W. B. Tripe	Census Officer, Dar es Salaam, Tanganyika	October 1949—November 1949

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PLANT PATHOLOGY DEPARTMENT

By F. C. Bawden

Dr. F. M. L. Sheffield who has held the post of cytologist in the department since 1929 left in October to join the staff of the East African Agricultural and Forestry Organization. Dr. F. M. Roberts was seconded in November to work for a year with the Clove Research Scheme in Zanzibar.

During the spring, the field station for research on sugar beet diseases was transferred from Hackthorn to more convenient and larger premises on an airfield at Dunholme Holt.

Dr. R. Hull attended two conferences, one in Belgium in February and the other in France in July, organized by the International Institute for Sugar Beet Research; Mr. F. C. Bawden attended the Fifth International Congress for Comparative Pathology, at Istanbul in May; Mr. H. L. Nixon attended the meeting of the Electron Microscope Society in Holland in July.

In March Mr. F. C. Bawden visited Zanzibar as a member of the mission sent by the Colonial Office to report on a proposed scheme for the control of sudden death disease of cloves.

Dr. P. H. Gregory was awarded the D.Sc. degree of London University.

Viruses and Virus Diseases

Laboratory and glasshouse work

The performance of the electron microscope was much improved by fitting new lenses and eliminating faults in the electrical system and its resolving power for favourable specimens is now about 2 mμ. It has been mainly used to study viruses but such varied subjects as insect cuticle, fungus spores and clay minerals have also been examined. Using the shadow-cast technique, the sizes and shapes of several viruses and virus strains were determined, some by the direct examination of clarified infective sap and others in purified preparations. Tobacco mosaic, potato X, potato Y, potato paracrinkle, tobacco etch, henbane mosaic, cucumber mosaic and cabbage blackring viruses all have rod-shaped particles of constant widths either about 10 mμ or about 15 mμ but variable lengths. Tomato bushy stunt, tobacco ringspot, a newly discovered virus from broad bean and the various tobacco necrosis viruses studied have spherical particles. Infective preparations of the Rothamsted culture of tobacco necrosis virus nave particles of two sizes, whereas crystalline, largely non-infective preparations contain only the smaller particles; the relationship between these two lots of particles is obscure. No specified particles were identified in the sap from plants infected with potato leaf roll, tomato spotted wilt, cauliflower mosaic, beet yellows and beet mosaic viruses, presumably because these occur too diluted or are similar in size and shape to normal host constituents. No virus particles could be detected in the contents of stomachs of infective aphids. The changes in properties of potato virus X during purification are correlated with the aggrega-

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tion of separate particles into extensive rope and net-like structures (101).

A previously undescribed virus found causing much damage to a crop of broad beans in the midlands showed some unusual properties. Sap from infected plants contains large quantities of a specific antigen not present in healthy beans, giving a precipitin titre of about 1/500, approximately the same dilution end-point at which sap also ceases to cause infections when inoculated to healthy plants. Although highly resistant to heat, sap still being infective after 10 minutes at 90°C., infectivity is lost in a fortnight at room temperature. All plant viruses previously studied are precipitated by one-third saturated ammonium sulphate solution, but the bean virus is not precipitated until the salt concentration reaches three-quarters saturation. It has been isolated in the form of a ribose nucleo-protein, which has not so far been made to crystallise.

A virus that appears to be related to tobacco ringspot, not previously known to occur in the British Isles, was obtained from a mottled syringa (*Philadelphus* sp.).

The loss of precipitating power of antisera to viruses and other antigens that occur during the early stages of heat denaturation is partially reversible. When the heated sera are incubated with trypsin the complexes, which were formed by antibodies uniting with other serum proteins, are disrupted and the antibodies liberated in a form in which they again precipitate their antigens.

With the development of a suitable method for applying statistical tests for significance to counts of local lesions, the effect of dilution on the numbers of lesions produced by viruses could be tested for compatibility with contrasting hypotheses. Experimental results fitted the hypothesis that variable numbers of virus particles are needed to produce a lesion at different sites and were incompatible with the previously held idea that lesions are produced by chance encounter between single virus particles and uniformly susceptible sites (100).

Considerable work was done with potato leaf roll. Infected tubers were freed from the virus when maintained at 37·5°C. in a humid atmosphere for periods of 20 days (99). *Datura stramonium* is more readily infected than potato by aphids; symptoms develop more rapidly and are more easily identified with certainty in the current season. Using *D. stramonium* as a test plant a series of experiments was started to gain information on the factors that influence the transmission of leaf roll virus by *Myzus persicæ*. Other viruses whose transmission by aphids was studied were pea mosaic, pea enation mosaic (96), cauliflower mosaic, cabbage blackring, sugar beet yellows and sugar beet mosaic. With some of those, more infections were caused by infective aphids if their feeding on healthy plants was repeatedly interrupted than if they were allowed to feed undisturbed. In an attempt to gain information on the feeding habits and movement of aphids, experiments have been started using plants containing radio-active phosphorus.

Experiments on the effects of host-plant nutrition on the susceptibility to infection and on the multiplication of certain viruses were concluded (88, 89). Reducing light intensity, increasing humidity and the amount of water supplied to host plants before inoculation increased their susceptibility to infection with

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several different viruses. Whether these effects reflect changes increasing the likelihood of injuries occurring at the time of inoculation, or changes in the constitution of cells that facilitate the establishment of virus particles, is uncertain. Such treatments appear to have little effect on the concentration of virus reached in infected plants. No evidence was obtained to support the claim of French workers that spraying infected plants with growth hormones greatly reduces virus multiplication. Sap from *Datura stramonium* plants infected with potato virus X, and from tobacco plants infected with viruses X and Y, which were severely deformed as a result of spraying with 2:4-dichlorphenoxy acetic acid or with 2-methyl-4-chlorophenoxy acetic acid, gave the same precipitin titres with virus antisera as sap from unsprayed plants; sap from sprayed and unsprayed plants also seemed equally infective and produced similar symptoms when inoculated to healthy plants.

Further work was done in attempts to find the nature of the cause of the yellowing disease that occurs in a Breeders' line of sugar beet, Family 41 (103). Seed from each of 20 single plants produced yellowed plants, but the extent and time of appearance of yellowing varied with different plants. Seed has been saved from the crosses green × green, green × yellowed and yellowed × yellowed, to see what influence the appearance of parent plants has on that of the offspring. Seed was also saved from Kleinwanzleben E plants that had been colonized with aphids from yellowed family 41 plants, to see whether the condition is transmitted through the seed of other lines of beet. Only 3 of 50 Klein E plants colonized developed symptoms, suggesting a much smaller rate of transmission than is usual with beet yellows virus.

Beta patellaris, *B. maritima*, a cross between the two, and two samples of polyploid beet, selected at Cambridge as possibly resistant or tolerant to yellows, were all susceptible and were infected by aphids as readily as commercial beet. There was some evidence that the type of symptoms, particularly whether or not there was etching of the veins or leaf necrosis, depended on the variety.

Evidence was also found for the occurrence of beet mosaic virus in strains of different virulence, one of which seems to cause the "silver-leaf" disease prevalent in some varieties of red beet. The same isolates of mosaic virus, however, may cause different symptoms in different varieties of red beet.

Sap from beet leaves contains material that inhibits the infectivity of beet mosaic, tobacco mosaic and various other viruses. It is destroyed by heating to 80°C., is non-dialysable and is absorbed on to activated charcoal. Its nature has not been determined but it can be precipitated and concentrated by the treatments previously used to isolate a virus-inhibiting glycoprotein from *Phytolacca decandra*.

In previous reports the underground spread of potato virus X from infected to healthy plants has been described and to gain further information on the manner whereby this occurs experiments have been made on the infection of plants through their roots. Roots of tomato seedlings became infected when they were directly inoculated with tomato bushy stunt, tobacco mosaic and potato X viruses, or when these viruses were added to soil or culture solutions in which plants were growing. Sometimes the viruses remained

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localised and multiplied only around their initial entry points, sometimes they invaded the whole root system but did not enter the aerial parts, and sometimes they produced a full systemic invasion of roots and shoots. When the roots of potato plants were inoculated with virus X, tubers set were often infected though the virus rarely spread into the haulm and caused symptoms.

FIELD WORK

There was the earliest and most severe attack of sugar beet yellows in 1949 we have yet experienced; on most plots all the plants were infected soon after singling and this unusually early and high incidence of the disease meant abandoning experiments designed to test the effect of varying plant population, and of introducing scattered sources of infection, on the incidence and spread of yellows. Beet mosaic was much less prevalent, and with this, as with yellows in previous years, reducing the density of the stand increased the percentage of plants that became infected. Contrary to general belief, uneven spacing had no effect on the incidence; the same percentage of plants became infected in plots carrying the same total of plants per unit area whether they were uniformly distributed or spaced irregularly with variable gaps.

Despite the dry summer, the irrigation of sugar beet had no effect on the aphid infestation or on the incidence of yellows and mosaic. Overhead watering did not wash the aphids off the plants and the peak aphid population was similar on irrigated and unirrigated plots. Early in the season more virus-infected plants were counted on the irrigated plots, but later there was no difference, and the effect is probably attributable to a delay in the development of symptoms in the unwatered plants.

The value of raising sugar beet stecklings in districts isolated from sources of yellows virus was again demonstrated. Four lots of stecklings from the north had less than 1 per cent. plants infected; four from Wales had 1, 1, 5 and 6 per cent. respectively, and one from Gloucestershire had 6 per cent., whereas four lots from the eastern counties all had more than 85 per cent. plants infected with yellows; the last also had considerably more plants with mosaic and downy mildew. Sowing under a cover crop of barley also reduced the incidence of yellows; seed sown under barley in April 1948 gave stecklings 11 per cent. of which had yellows compared with 87 per cent. and 100 per cent. for a July and September sowing without cover.

Spraying with some of the new systemic insecticides gave useful results in reducing the prevalence of yellows in the seed bed. Stecklings were sprayed from one to three times in the autumn of 1948; in June 1949 85 per cent. of the unsprayed plants were infected whereas those sprayed three times with E 605 had 10 per cent., with Pestox III 23 per cent. and HETP 41 per cent.; octachlor and nicotine were much less beneficial. With all the insecticides, the first spraying was least beneficial and the last the most. Experiments with insecticides on the root crop in 1949, like those on plant population, gave no useful results as yellows was too prevalent on the plots before the treatments had time to operate.

In an attempt to find lines of beet resistant or tolerant to yellows, more than 700 different lots were grown on a plot surrounded

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by infected seed plants. The lines which had the largest proportion of healthy looking plants and showed least yellowing have been selected for further study.

In potatoes, as in sugar beet, there was an unusually early and extensive spread of viruses. The populations of *Myzus persicæ* on the early spring hosts were higher than for many years and large numbers migrated to potatoes in late May. There were also many winged *Macrosiphum euphorbiæ*, *Aphis rhamni* and *A. fabæ*, but the large numbers of predators and parasites that soon developed prevented the production of a large infestation of apterous aphids. Overhead irrigation greatly increased plant size and yield of tubers, but did not affect aphid populations, which were uniformly small. The aphids present were uniformly distributed per area of land and not per plant, so that plants spaced three feet apart carried twice as many as those spaced 18 in. and four times as many on those spaced 9 in. DDT, E 605 and Pestox III sprayed at weekly intervals controlled aphids but their effects on the spread of viruses will not be known until 1950.

Records on the health of plants grown from tubers saved from experiments in 1948 showed that leaf roll spread as readily to potatoes surrounded by sticky barriers, which prevented the passage of wingless aphids, as to those not so protected, suggesting that spread is largely occasioned by winged forms. Virus Y also infected nearly as many protected as unprotected plants. Experiments on the effects of roguing again showed that the removal of diseased plants in mid-June was too late to prevent most of the spread of viruses, except for potato virus Y in Derbyshire. The experiment on effects of planting date and manurial treatment showed that viruses spread equally in plots planted at different dates, though the later ones had fewer aphids. Plots with phosphate had significantly more aphids, but the only effect of manuring on spread of virus diseases was, as previously found, that most plants became infected on plots that received dung.

An analysis of the results of experiments made in different parts of England and Wales between 1941 and 1947 showed that the spread of leaf roll is correlated with the number of winged *Myzus persicæ* caught on sticky traps throughout the season. Spread of virus Y is also correlated with these trap catches, but to a lesser extent (93).

Mycology

A wind tunnel designed for use in studying various problems in plant pathology such as the dispersal and deposition of fungus spores and protectant dusts, and aphid flight, was completed and put into operation. It is designed to work at wind speeds from 10 to 0·1 metres per second. So far tests have been made mainly on the deposition of Lycopodium spores on sticky cylinders of various diameters from 0·2 to 2·0 cm. At wind speeds from 1 to 10 M/s, the efficiency of the traps increases as the cylinder diameter is reduced and the wind speed is increased. This had been predicted by workers on aerodynamics, but has not previously been studied quantitatively. The large increase in efficiency at low speeds for very narrow cylinders that has been found, however, seems to be unpredicted.

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Tests on the efficiency of spore traps in the open give similar results to those in the wind tunnel; they also show that there is a greater deposit of spores per unit area on vertical than on horizontal surfaces and that the traps are more efficient with the large spores of Lycopodium (30μ diam.) than with the small spores of Lycoperdon (4μ diam.).

A routine spore trap operated continuously in the open showed that there were not the heavy showers of either powdery mildew or *Alternaria* sp. that occurred in 1948.

Studies were continued on the effects of cultural treatments on wheat with and without eyespot (*Cercosporella herpotrichoides*). With plants grown in pots out of doors, eyespot reduced yield by 23 per cent. when ammonium sulphate was given and by 41 per cent. when it was not. Under glass, it reduced yield by 26 per cent. when nitrate was applied and by 90 per cent. when it was not. Applying nitrogen in March and April increased yields of both infected and uninfected wheat more than applications in May. In the field, spring spraying with sulphuric acid increased yields by 4·4 cwt. of grain per acre when applied to plots receiving ammonium sulphate compared with 1·9 cwt. with those that did not.

Depth to which the fungus penetrates leaf sheaths was used to measure the relative susceptibilities of 12 cereals to eyespot. There were slight differences between the seven wheat varieties tested, but all were more susceptible than oats, and rye was less than oats. *Triticale*, a wheat rye cross, was intermediate between the two parents. Whereas infection caused an average loss of 50 per cent. of grain yield in the wheat varieties, rye and oats suffered no loss.

A culture of *C. herpotrichoides* isolated from a crop of oats in Bedfordshire that was severely attacked, was as pathogenic for wheat as cultures derived from wheat, but it was more pathogenic for oats. *Lolium italicum* and *L. perenne* and *Dactilis glomerata* were infected with *Cercosporella herpotrichoides* isolated from wheat; the fungus was re-isolated from each of the grasses and found to be still pathogenic for wheat.

The survival of resting spores of *Plasmodiophora brassicæ* under various crops was again tested, but the previously reported effects of brassicæ in reducing survival were not again obtained. Studies on the relation between spore concentration in the soil, the number of root-hair infections per plant, and the proportion of plants that develop clubs, shows that clubbing can result from a few infected root hairs, and it seems that a club may develop from a single infection.

Some preliminary experiments on factors affecting the production of rhizomorphs by *Armillaria mellea* confirmed the part played by genetical factors but also indicated that the carbon/nitrogen ratio in the medium is important. Rhizomorphs were formed most abundantly with a moderate carbo-hydrate supply and little nitrogen.

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BIOCHEMISTRY DEPARTMENT

By N. W. Pirie

Investigation of Leaf Components

Several years of work on the effect of enzymes from various sources has now been rounded off sufficiently for it to be written up. The essential features were summarised in last year's report.

By following the reduction in viscosity of a solution of a soluble cellulose derivative under standard conditions, Tracey has detected the presence of cellulase in saps from a number of plants. The enzyme is present in very small amounts in tobacco leaf sap, its concentration often being less than a one hundred thousandth that in snail digestive juice (the usual source of cellulase used in this department). In tobacco root sap the concentration may be five or ten times as great. It appears that the enzyme is relatively more abundant in young leaves than in old. By using large amounts of fresh active root sap it has been possible to show that finely dispersed cellulase is also attacked by the enzyme.

The readily sedimentable phosphorus-containing protein that is a characteristic component of the fresh sap of young tobacco leaves has now been found to contain several enzymes. These will not only act on extraneous substrates e.g. phosphate esters, but also bring about the denaturation of the protein itself and the liberation from it of nucleotide and, subsequently, the dephosphorylation of the nucleotide.

Large scale preparation of leaf protein has been started at the Grassland Improvement Station where a mill capable of handling up to 2 tons of fresh leafy material has been installed. This works satisfactorily, and we have now sufficient skill in its use to be able to grind any of the leaves grown in normal agricultural practice and to liberate about half the protein.

Investigations on tobacco necrosis virus have continued along the lines set out in last year's report and some progress has been made towards getting conditions defined, so that the results will be repeatable. Some of the important variables have been recognised, but the frequency with which unexpected activations, or inactivations, occur suggests that we have not recognised all of them.

Oxidation of Mn by Peroxidase Systems in Plant Extracts

The system consists of peroxidase, and a peroxidase substrate. Using partially purified peroxidase preparations, the effect of variation in the peroxidase, phenolic substrate and H_2O_2 concentration has been studied. The oxidation of Mn can be demonstrated at Mn concentrations likely to be present *in vivo*, and with a few μg. of peroxidase. The Mn probably reduces the oxidised peroxidase substrate, and thereby is itself oxidised. This involves the substrate in a cycle of oxidation and reduction. The catalytic activity of the substrate is demonstrated by the fact that under suitable conditions 1 μg. of p-cresol produced 605 μg. Mn_2O_3.

Preliminary evidence has been obtained that the oxidized Mn is reduced by plant metabolites. This is an agreement with the

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hypothesis previously put forward that a Mn oxidation reduction cycle is responsible for the effect of Mn on plant respiration.

The oxidation of Mn *in vivo* by this system depends on the production of H_2O_2 by the plant tissues. It is known that H_2O_2 is formed in several oxidation reactions catalyzed by enzymes, e.g. xanthine oxidase and amino acid oxidase. Preliminary evidence has been obtained that H_2O_2 formed by these enzymes may be used by peroxidase systems to bring about the oxidation of Mn.

The possibility that the peroxidase system can oxidize metallic ions or complex ions other than those of Mn is being investigated.

Under certain conditions the addition of small amounts of salts of Mo, V and W have been found to accelerate the rate of oxidation of Mn by peroxidase systems. There is evidence that this is due to the enzyme catalyzed formation of peracids, e.g. the formation of permolybdate from molybdate. These experiments may throw light on the mechanism of peroxidase action and the physiological role of Mo.

The rate of oxidation of ferrocyanide by H_2O_2 is increased by peroxidase alone, but peroxidase together with suitable substrate produces a much more striking increase in the rate of oxidation. The oxidation of ferrocyanide is accompanied by consumption of H^+, and may be followed manometrically by CO_2 uptake in bicarbonate medium in an atmosphere of $N_2 + CO_2$.

Hydroquinone—and Hydrosulphite—Soluble Manganese of Organic Soils

It has been suggested that manganese deficiency occurring in soils with total manganese contents adequate for plant growth is due to the presence of the soil manganese higher oxides in unreactive forms. The highly reactive and potentially readily available fraction has been defined as the fraction dissolved by 0·2 per cent. hydroquinone in M-ammonium acetate at pH 7, and a moderately reactive fraction as that dissolved by hydrosulphite under the same conditions. Heintze and Mann have shown that manganese extracted from neutral or alkaline organic soils by M-ammonium acetate containing 0·2 per cent. hydroquinone at pH 7 may represent only a small percentage of the soil manganese higher oxides reduced by hydroquinone during the extraction. This is due to the retention by the soils of part of the divalent manganese formed by reduction. The amount of manganese retained in this way depends in general on the organic content of the soil. Results with the manganese minerals, pyrolusite, hausmannite, and manganite support the view that under certain conditions hydroquinone and hydrosulphite may be suitable reagents for differentiating between manganese higher oxides of different reactivity. But since hydrosulphite, unlike hydroquinone, partially prevents retention of divalent manganese by soils, differences between hydrosulphite and hydroquinone soluble manganese, on organic soils in particular, may be due not to the reduction of manganese higher oxides of different reactivity but to differences in the amounts of divalent manganese retained by the soils.

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Resistant Components of Soil Fungi

Work started in October on the chemical nature of the mycelia of some representative and easily available fungi. This will later be extended to the examination of those that are prominent in soil to see whether it is likely that they contribute significantly to the building up of "soil organic matter."

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NEMATOLOGY DEPARTMENT

By T. Goodey

General

Nowhere at the present time is it possible for the worker in applied biology to obtain instruction in the handling of plant and soil nematodes. The need for a course in nematology and nematological methods and techniques has been urgent for several years. At the request of the Plant Pests and Diseases Committee of the Association of Applied Biologists the staff of this department agreed to be responsible for conducting a course during the past summer. By permission of Sir Frank Engledow it was held at the School of Agriculture, Cambridge, from July 7-16, 1949. Mr. F. G. W. Jones, Entomologist in the School of Agriculture, made the necessary local arrangements and secured accommodation at Jesus College for the 30 students who attended. Selection of the students (20 of whom were from the National Agricultural Advisory Service) was carried out by the staff of the Ministry of Agriculture Plant Pathology Laboratory, Harpenden and Mr. E. Dunn, Assistant Entomologist of that laboratory acted as secretary/treasurer. A strenuous 10 days of intensive lectures and practical work was spent by those conducting and taking the course, the first of its kind to be arranged in this country. The many letters of appreciation and thanks received from those who took the course show that it was successful.

Dr. T. Goodey paid a short visit to Holland from April 26 to May 6, 1949 and spent most of the time at Wageningen in Professor H. M. Quanjer's Laboratory for Mycology and Potato Investigations. Here Mr. J. W. Seinhorst has been working for some years on problems connected with stem eelworm disease ("stock") of rye and has devised new methods for extracting the infective larvæ of the parasite, in large numbers, from dried infested rye plants and for cleaning and concentrating them. Details of these methods have not yet been published but Mr. Seinhorst kindly supplied particulars for the construction of the apparatus and gave details of the methods he has successfully developed. Similar apparatus has now been erected in this department and is in full working order. It has provided us not only with large numbers of infective larvæ of several races of the stem eelworm from teasel, oats, red clover, narcissus, and broad beans, which will be used in due course for inoculation experiments, but also with *Aphelenchoides* species from strawberry buds, violet plants and chrysanthemum leaves. On leaving Wageningen a short stay was made at the Bulb Research Station, Lisse where a profitable opportunity was taken for discussions on nematode infestations of bulbs with Professor E. van Slogteren and Dr. M. P. de Bruyn Ouboter.

Dr. Peters attended an Arable Conference at St. Helens in January and gave a talk on potato root eelworm, illustrated by the C.O.I. documentary film.

During the year two temporary workers have spent periods in the department learning nematological methods, namely Mr. R. S. Pitcher of East Malling Research Station and Mr. Sven Bingefors of the Swedish Seeds Association, Uppsala.

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On the area adjacent to the laboratory our living museum of plant parasitic species and races of eelworms is now largely established and cinder paths have been made between several small plots. The two greenhouses have been fitted with an electric heating system, concrete paths have been laid, staging erected in one of them and ventilators fixed in the side walls.

Research carried out by the members of the staff falls naturally into two main sections: (1) problems connected with plant infestations by eelworms belonging to the families Tylenchidæ and Aphelenchidæ and soil nematodes generally (Dr. T. Goodey, Dr. Mary T. Franklin and Mr. J. B. Goodey), (2) problems connected with root-infesting nematodes belonging to the family Heteroderidæ, (Dr. B. G. Peters and Mr. D. W. Fenwick).

Tylenchidæ and Aphelenchidæ

Tylenchidæ

Dr. Goodey has carried out investigations on stem eelworm (*Ditylenchus dipsaci*) attacks on the fuller's thistle or teasel (*Dipsacus fullonum* L.) with a view to determining the route taken by the parasite in reaching the flower head and thus becoming dispersed in and on the seed in a dry quiescent but viable state.

He has written a booklet entitled "Laboratory Methods for Work with Plant and Soil Nematodes" which has been published by the Ministry of Agriculture and Fisheries as Technical Bulletin No. 2.

He has also revised much of the text and prepared further illustrations for his new book, "Soil and Freshwater Nematodes" which is now passing through the press and should be issued about mid 1950.

Mr. J. B. Goodey reports that work has been continued on the plant-parasitic species of *Ditylenchus*. The host-list of the Stem eelworm, *D. dipsaci*, contains the names of some 350 plants and a beginning has now been made in trying to find out which biologic race is responsible in each particular infestation. *D. destructor* the potato tuber-rot nematode has been shown to be the cause of eelworm disease of bulbous iris, hitherto ascribed to *D. dipsaci*, and further experiments are now in progress which show that *D. destructor* attacks several other hosts as well as the few already known. Some new biological aspects of the life cycle of *D. destructor* have been discovered. A paper embodying the results of these investigations has been prepared.

Reports of attacks by *D. dipsaci* on strawberry have been numerous recently and work has been carried out on the subject. It has been shown that the nematode will transfer from strawberry to oats, but it is suspected that the problem is more complex and that races of *D. dipsaci* other than the oat race may be involved.

During work on the fine details of the anatomy of D. *destructor*, a new structure was discovered on the ventral surface of the eelworm. Its function is not known but it has been found on several other [illegible] of the super-family Tylenchoidæ. A short paper describing [illegible] and distribution has been written in which the term [illegible]id' is proposed as its name.

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An interesting case of *Calceolaria integrifolia* attacked by *D. dipsaci* was received during the summer in which the eelworms were themselves parasitized by a nematode-attacking fungus. Its mode of attack and development on *D. dipsaci* has been observed and the fungus isolated in pure culture. The fungus has been identified provisionally as a species of *Acrostalagmus*, possibly an undescribed one. Work on this is being continued.

By courtesy of the Chemistry Department many specimens of Conifers, particularly Sitka spruce, have been examined for the presence of certain nematodes which have been reported attacking roots of Conifers in U.S.A. A species of *Hoplolaimus*, identified as *H. uniformis* Thorne, 1949 the first record of this eelworm in Great Britain, has been found in considerable numbers. A few specimens had their heads buried in the root tissue. The matter is being pursued further, but it is considered doubtful whether the eelworms cause any but trivial damage.

Work designed to find a fixative causing little or no shrinkage of eelworms has been continued. The result, a new formal-acetic mixture, has been incorporated into a joint paper with Dr. Mary T. Franklin in which the use of dilute Cotton Blue in Lactophenol as a medium for the rapid mounting of plant parasitic nematodes, has been described. Further work on mounting media is proceeding.

Aphelenchidæ

Dr. Mary T. Franklin reports that further investigations on the two species of *Aphelenchoides* found in strawberry plants have shown them to be *A. fragariæ* and *A. ritzema-bosi*. Reference to Ritzema-Bos's original descriptions of *A. fragariæ* (1891) and *A. olesistus* (1893) have failed to show sufficient difference between them to justify the separation of the second species, moreover the successful inoculation of a fern with *A. fragariæ* from strawberry, with the production of symptoms typical of infection with *A. olesistus*, has shown that the same nematode can parasitize both plants, therefore *A. olesistus* is regarded as a synonym of *A. fragariæ*. The other species found in strawberry resembles the chrysanthemum eelworm in morphological characters and is therefore considered to be *A. ritzema-bosi*. Cross-inoculations of these worms have been made from strawberry to chrysanthemum and *vice versa*, but they have not so far yielded results. The determination of the identity of these two species in strawberry was helped by the exchange of specimens with Dr. Merlin Allen of California.

Work has continued on the blackcurrant eelworm: blackcurrant bushes infested with *Aphelenchoides ribes* have been established on the plot and a beginning has been made in studying the biology of the parasite with a view to finding out the periods of maximum activity and of migration. It has been established that the nematodes may be found wandering on the branches in wet weather in summer and also that they will move upward against a downward trickle of water. Six varieties of blackcurrant and also one each of red currant and gooseberry have been planted next to the infested blackcurrant bushes to determine their susceptibility to infection with *A. ribes*. The past hot dry summer hindered the establishment of the bushes, but it is hoped that they will make good growth during the coming year.

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Small-scale warm-water treatments having established the lethal temperatures for *A. ribes*, warm-water treatments of un-rooted blackcurrant cuttings have been started with a view to finding a suitable treatment which could be used in the starting of a clean stock. The treatments used (at the beginning of December), namely, 46°C. for 25 min., 47°C. for 20 min., 48°C. for 15 min., and 49°C. for 10 min., have caused sprouting of the buds, but it is too early yet to say whether roots will be produced normally.

Cross-inoculation experiments have shown that *A. ribes* from blackcurrant can become established on strawberry plants and *A. ritzema-bosi* from strawberries on blackcurrant seedlings with the production of lesions typical of eelworm damage. Further studies of morphology and host range are being made to determine whether *A. ribes* should be regarded as a synonym of *A. ritzema-bosi*.

Violet plants infested with what must now be called *A. fragariæ* have been established on one of the plots. It has been found that the worms may be present in damaged flower buds and that the dried seed may also be infested with eelworms which become active on soaking in water.

Cultures of species of *Aphelenchoides* on agar together with fungus have been continued. *A. fragariæ* from fern has become established and also *A. parietinus*, a species commonly found in decaying plant material, which has been thought to be parasitic in some cases.

In collaboration with J. B. Goodey a new technique for processing, staining and making permanent mounts of the smaller nematodes has been developed. By transferring nematodes from fixative to lactophenol containing cotton blue at a temperature of 65-75°C. they can be cleared, stained and mounted in lactophenol in a few minutes instead of requiring several weeks in slowly concentrating glycerine. The new method is particularly useful with *Aphelenchoides* which are very easily distorted when processed by the older method.

HETERODERIDÆ

Dr. B. G. Peters reports as follows: The distribution of potato root eelworm in England suggests that peaty soils, sands, and silts are favourable and heavy clay soils unfavourable to the parasite. An investigation of these edaphic factors has been started by adding a light infestation of the eelworm to an unpromising subsoil clay, factorially modified by the addition of sand, peat, compost and mixed artificials, in which potatoes were grown in 32 large glazed pots. In the first year plant responses were not significant in terms of height of haulms at 45 days (beyond a suggestive 2·8 cm. increase from compost), or of number of tubers harvested; but weight of tubers showed a significant response to compost, peat, and fertilizers in that order, with no evident interaction effects. Counts of eelworm cysts and larvæ are not yet completed. The experiment will be continued.

Nematocidal investigations have continued on a laboratory scale and also in pots of soil grown outdoors. In the outdoor experiment 40 8-litre glazed pots, filled with soil naturally infected with *H. rostochiensis*, were injected in pairs at rates of 0, 1, 4 and 16 ml. per pot of the following: (1 & 2) two chlorphenol products, (3)

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ethylene dibromide 5 per cent. v/v. in solvent naphtha, (4 & 5) D-D mixture. Apart from one set of 8 D-D pots (required for other purposes), a potato was grown in each pot. The chlorphenol materials at the rates used gave rise to no plant responses of any kind. Both ethylene dibromide and D-D at the highest rate caused a marked reduction in the height of haulms after 21 days and the yield of tubers was significantly higher at 1 and 4 ml. than at 0 and 16 ml.

A start has been made on determining the rate and direction of migration of potato-root eelworm larvæ through soil, both vertically and horizontally. To measure vertical migration, potatoes were grown in wooden boxes made by superimposing six 2-inch-high sections, 6 in. square in plan. Eelworm cysts were added at the top of some boxes and at the bottom of others. Leaching effects were controlled by watering some from below and others from above. The soil from each 2-in. section was separately collected and awaits eelworm counts.

The use of vinegar eelworm as a test animal in the preliminary selection of possible nematocides has been investigated in some detail. These eelworms are readily cultured in vinegar, neat or diluted with water, or in solutions of sucrose or ethyl alcohol or both, at temperatures up to 37°C. Living worms show a marked negative geotaxis which is made use of in concentrating them from a culture into a clean medium.

With time and temperature fixed, they are exposed to different concentrations of a nematocide in aqueous solution or emulsion. They are counted by sampling in a 1-ml. counting chamber on the haemacytometer principle. After exposure the number dead is also estimated by sampling, but many nematocides cause lysis of the worms to an extent depending on the concentration. At low kills it is impracticable to count living worms and accordingly, after estimating dead worms, sufficient iodine is added to kill the living and a further estimate is made of the total. The difference between "dead" and "total" estimates the living, and the difference between "living" and "exposed" estimates the kill. At high kills the living worms are sluggish and can be counted.

In spite of the superimposed sampling errors involved in a single estimation it is possible to secure reproducible results giving a tolerable rectilinear relation between probit and log concentration. Thus, a sample of D-D mixture emulsified with Triton N.100 has given at 32°C. a 20-hour L.D.$_{50}$ of about 24 p.p.m. by volume.

This technique has been applied in an investigation, suggested by Dr. Thornton, of the nematocidal power of D-D repeatedly injected into soil at fortnightly intervals. The soil was subsequently leached with water, to which leachings vinegar eelworms were exposed. Preliminary trials indicate that, instead of a progressive accumulation of toxic material in the soil, leachings from successive injections give progressively lower kills.

Continuing the joint experiment (with the West Norfolk Farmers' Co-operative and Shell) on the effects of annual injections of D-D on a field scale, at Moulton and Prickwillow, the second-year yields of potatoes reveal the following results. At Moulton there was no significant difference between plots injected in 1947 only and

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uninjected controls, but plots injected in 1948 gave a higher yield. At Prickwillow, on the other hand, there was no difference between 1948-injected plots and the controls, whereas 1947-injected plots gave a significantly lower yield. At both sites the response to D-D this year was very much less than it was last year.

Regarding other species of *Heterodera*, soil samples taken in the autumn of 1948 from all the Barnfield plots have been processed, but the counts of *H. schachtii* cysts per g. and of eggs and larvæ per g. of soil have not yet been analysed.

Mr. D. W. Fenwick reports that six principal lines of research on *Heterodera rostochiensis* have been followed during the last year.

Viability determinations

The investigations into the hypochlorite technique mentioned in the previous year's report are almost complete. The method of arriving at a reliable total count of eggs plus larvæ per cyst has been written and accepted for publication. A further refinement resulting in a saving of at least 60 per cent. in time has been introduced by Miss E. Reid and is published as an appendix to the paper.

Larval emergence

The problem of larval emergence has received considerable attention and has been investigated from the point of view of "in vitro" laboratory experiments as well as in pots of soil. A preliminary stage to "in vitro" experiments has been the investigation of variability and this forms the subject matter of a paper at present in the press. As a result of this work it is now possible to set up experiments and obtain results of a predictable accuracy and thus ensure that effects of any given magnitude can be detected with a reasonable degree of certainty.

Investigations into the form of the hatching curve are now complete and have been recorded and are accepted for publication. The sigmoid nature of the curve has been established as a sufficiently close approximation for probit analysis to be practicable. Using this, it is possible to define any hatching curve by means of three constants (1) the total number of larvæ liberated, (2) the time at which 50 per cent. of the larvæ have emerged, corresponding to a probit value of 5, (3) the standard deviation of the hatching time, corresponding to the slope of the probit line.

Experiments have been conducted with anhydrotetronic acid, which is very active in inducing larval emergence. Its effect under different conditions is being investigated with the object of determining an optimum. One complication regarding its use is that two different samples of the chemical appear to have behaved differently. The first manifested its maximum activity at 1:2000, at which it was only slightly less active than was the root diffusate. The second sample, however, appeared to be most active at 1:1000 and its maximum activity appeared to be considerably less than that of the previous sample. The first sample in solution in distilled water gave a pH of between 5 and 6 but the second in solution gave a pH of between 2 and 3, and this discrepancy is now being investigated. Great importance is attached to experiments on this chemical since its action appears to be very similar to that of root diffusate,

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and it is hoped to utilize it finally as a standard against which samples of diffusate can be tested.

A considerable amount of preliminary work has been carried out on the problem of larval emergence in soil as well as on the degree of persistence of root diffusate in soil. In the former case a large scale preliminary experiment has been conducted in which potato plants of three varieties were grown in a 3:1 mixture of loam and sand. Leachings from these plants were drained into three types of naturally infested soil. It was found that leachings from soil alone resulted in a 50 per cent. hatch, whilst in the case of potato leachings about 86 per cent. of the larvæ emerged. Significant differences were found to exist between soils and there was evidence of differences in degree of emergence due to leachings from different host varieties. A paper has been written on this subject and has been accepted for publication. Further experiments are in progress on the persistence of root diffusates in soil.

Population fluctuations

Parallel with experiments on larval emergence a series of experiments has been conducted to investigate fluctuations in eelworm populations during the growing season. This has been approached from two angles (1) estimation of the gross changes occurring in the whole population and (2) the rate of penetration of larvæ into new hosts.

Factors influencing larval penetration

Repeated failure to obtain infections by inoculating larvæ into clean soil containing growing potato plants resulted in making a simple experiment on the effect of different conditions on the penetration of eelworm larvæ. It was found impossible to infect plants grown under greenhouse conditions and very few cysts developed on plants grown in full sun. The highest yield of cysts was obtained from plants grown in the shade and in gravel plunges. It is believed that this result is a temperature effect, the high temperatures attained in a greenhouse being detrimental to larval penetration. Further experiments on this are contemplated in the coming season.

D-D experiments

A number of small scale experiments have been carried out on the soil fumigant D-D. The results of experiments mentioned in last year's report on the apparent unreliability of the "buried bag" technique are now complete and a letter has been written to "Nature" on this matter.

"In vitro" experiments are in progress on the nematocidal effects of D-D under different physical and chemical conditions. The effect of humidity has been investigated; and it has been found that a high humidity is essential for maximum effect.

An experiment has been carried out on the nematocidal properties of four different samples of D-D. It has been found that the samples exhibited significant differences in nematocidal properties, these differences being most marked at high mortalities. It was found that 7 times as much of one sample as of another was needed to secure a 99 per cent. kill. The results of these experiments have been recorded and accepted for publication.

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Fungi infecting Heterodera *cysts*

In conjunction with Mr. C. L. Duddington of Regent Street Polytechnic, an investigation is in progress on the identity and biology of fungi found infecting *Heterodera* cysts. A number of these have been identified and there can be little doubt that at least one is present as a natural infection within the cyst. Attempts are being made to find a fungistatic agent which will prevent the development of these fungi in hatching experiments. The possibility of using these fungi on a field scale as a method of biological control is being considered.

In conjunction with Dr. Mary T. Franklin the analysis of data on the larval lengths of different species of *Heterodera* is complete and has been accepted for publication.

Co-operation with Dr. H. C. Gough of Cambridge in long term investigations on eelworm population changes during crop rotations on different soils is also continuing.

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ENTOMOLOGY DEPARTMENT

By C. B. Williams

Staff

During the period Mr. R. A. French joined the staff as an Assistant Experimental Officer, Dr. G. O. Evans has worked on a grant from the Forestry Commission, and Mr. J. E. Satchell has worked since August, 1949 on an Agricultural Research Council Scholarship. Mr. C. J. Banks also came to work early in 1949 on a research grant for the Agricultural Research Council to study Biological Control, but unfortunately was taken ill shortly afterwards and was not able to resume his investigations during the year.

Insect Ecology

Dr. Williams has continued his work on the relation of insect abundance to weather conditions. Trapping, on which this work is based, was continued throughout the year in three traps—bringing the post-war period of trapping to $3\frac{1}{2}$ years. Trapping will be stopped early in 1950 when the fourth post-war year is completed. All the work of the year supports the previously published results on the relation of activity to weather conditions. Insects are, in general, more abundant after wet weather in the summer and after warm weather in the winter.

Work was continued on the relative abundance of different species of insects in random samples of wild populations, with particular reference to the interpretation of the frequency distribution either as a logarithmic series or a log-normal distribution. A big experiment carried out in July 1949 unfortunately gave inconclusive results.

Many of the results of these investigations have been found to be applicable to botanical problems and a paper is in the press discussing the relation of the logarithmic series to quadrat sampling of plant.

Work on migration of insects continues chiefly through the co-operation of naturalists in different parts of the world. There was no outstanding immigration of pests into Britain during 1949.

Gall Midges

Dr. Barnes reports that the expected fall in numbers of the wheat blossom midges in 1949 took place, there being 7,698 larvæ of the species in the 500 ear samples as compared with 15,417 in 1948. The percentage grain attack fell from 14·7 to 7·7. The year 1949 was not such a good one for emergence as was 1948 and the weather at the time of oviposition was not particularly favourable. The descent of the larvæ from the ears took place about 17th July which was about the same as in 1946 and 1947, but earlier than in 1948, and later than in 1945, a particularly early year.

His investigation of *Contarinia nasturtii* was particularly successful. He was able to rear this midge obtained from the blossom of *Rorippa amphibia* both on the blossom of this plant and of swedes, and also midges from rape leaves on turnip, radish, swede and cabbage leaves as well as on the blossom of radish. The cross between midges obtained from *Rorippa* blossom and rape

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leaves proved fertile, the offspring being reared successfully on turnip leaves and *Rorippa* blossom. It can therefore now be stated that *Contarinia nasturtii*, the swede midge, will both cause blossom and leaf damage on cultivated Crucifers and that only one species of midge is involved.

The general work on the biology of gall midges has continued; species on sweet chestnut, wheat, barley and among lettuce, poppy and Calendula seed having been reared and over 1,000 slides having been added to the collection. Volume 6 of Gall Midges of Economic Importance dealing with those attacking Miscellaneous Crops was published on 15th September, 1949. Mr. C. S. Tsi of the National Peking University spent the last month of the year studying gall midges with Dr. Barnes.

Slugs

The ecological investigations on slugs has mainly been concentrated on two particular lines. A nightly (for 214 successive nights and at intervals subsequently) study was made on a population of 1,000 individuals of the Grey Field Slug introduced into a garden where this species was previously absent although it was the dominant species in surrounding gardens. The study showed that this species of slug was able to maintain itself and breed successfully in this garden and that apparently its previous absence was probably due to the very great drying-out capacity of the soil (due to lack of humus). This lack has been diminished during recent years, but the drought of 1949 nearly caused a complete wipe-out again. This diminution in numbers during the summer and autumn of 1949 was also apparent in neighbouring gardens, although other slug species (perhaps thicker skinned) did not show a similar reduction in numbers due to the lack of moisture. This study also emphasized the differences in temperature in the various parts of a typical garden, under walls, plants, trees, etc., with the result that individual Grey Field Slugs were seen active on all but five nights during the winter of 1948-49.

The other particular investigation on slugs was a preliminary experiment in marking slugs by painting the shell of *Testacella* with cellulose acetate paint. Two groups were marked and such individuals were seen fairly regularly for about a month after marking but more infrequently later. One marked individual was, however, observed a year but a day after marking. If a satisfactory method can be found it will make possible studies of absolute populations.

Additional information was gathered concerning the life history, breeding, mating periods, etc. of several species of slugs.

Population Growth and Diurnal Periodicity of *Aphis fabæ*

Dr. Johnson reports that with two disc suction traps operating over a bean field and near a sugar beet crop, an hourly record has been obtained over a period of 6 weeks of the fluctuations in population and activity of the bean aphis and many other species. At the same time hourly records of wind-speed, temperature, hours of sunlight and rainfall have been taken. Together with these data the population growth on the crop has been studied and work

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is in progress on the analysis of population and activity in relation to meteorological conditions.

COMPARISON OF TRAPS

Further work on the comparative performances of sticky traps and suction traps was undertaken.

MOVEMENTS OF INSECTS IN THE UPPER AIR

It has been shown during 1948-1949 that the aerial tow-nets normally used for studies and in use also at Cardington are subject to very grave sampling errors. This has necessitated a revision of trapping methods particularly those in use at Cardington. Special suction traps have been designed and constructed which will be used for aerial-drift studies at Cardington in 1950.

Much of the time in 1948-9 was occupied in analyzing and writing up the work of the last three years.

Dr. Raw reports as follows:—

CHAFERS

A study of the ecology of the garden chafer, *Phyllopertha horticola*, which was begun at Bristol was completed after appointment to the staff at Rothamsted. A thesis embodying the results of this study was accepted by the University of London in June 1949 for the Ph.D. degree. This work is now being redrafted for publication.

WIREWORMS

The changes in wireworm population under leys are being studied in the ley and arable rotations experiments in Highfield and Foster's Field. These experiments enable the problem to be studied under a variety of leys on the same soil type beginning, in Highfield, with a relatively high population from the permanent grassland, and in Foster's Field with a low population from the old arable land.

In collaboration with the Insecticides Department, plots in the wireworm experiment on Hoosfield were sampled to estimate the effect of the chemical treatments on the wireworm populations. It was found that the wireworm population fell rapidly on all the plots during the course of the experiment and this, together with the practical difficulty of making an accurate estimate of a relatively low wireworm population on arable land, masked any treatment effect which may have occurred.

EARTHWORMS

The cultures from the life history studies begun by Dr. A. C. Evans were kept going pending the appointment of a full time worker to continue the earthworm work. In the spring of 1949 Dr. Doeksen from Wageningen visited the Department and demonstrated an electrical technique for bringing earthworms to the soil surface. If this technique can be developed for quantitative work it will be a valuable aid to ecological studies.

In collaboration with Mr. Garner's Department, an exhibit on earthworms was staged at the Chelsea Flower Show in May 1949.

In August, 1949 Mr. J. E. Satchell was appointed to the department on an A.R.C. scholarship and will continue the work on earthworms, particularly the development of the electrical sampling technique.

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Dr. G. Owen Evans reports as follows :—

TICKS

During the early part of 1949 the results of investigations on the ecology of *Ixodes ricinus* in Wales were prepared for presentation to the University of Wales for the degree of Ph.D. The thesis was successfully submitted in April and three papers on this work are now in press.

INVESTIGATIONS ON THE FAUNA OF FOREST SOILS

The major part of the field work has been conducted at the Forestry Commission's Nurseries at Ampthill, Bedfordshire. The chief project is the investigation of seasonal fluctuations in the soil fauna of a Spruce and Oak Forest. A study of this nature involves two fundamental problems, namely, the extraction and the identification of the fauna.

Extraction

A comparison of the Berlese and the Floatation Method, using 30 samples (soil and humus) 2 in. in diameter and to a depth of 3 in. from 4 sq. ft. of the floor of a spruce Forest, showed that there was no significant difference between the yields of arthropods above 0·5 m.m. in length. The Berlese technique was more satisfactory for smaller arthropods. This was probably due to the destruction of minute Acari during the washing process and the passage through the sieves (180 meshes to 1 in.) used in the floatation process. Extractions by the Berlese method from the Spruce stand in November yielded an estimate of 1,100 million arthropods per acre (to a depth of 3 in.) of which 330 million belonged to the Class Insecta and the remainder to the Arachnida.

Identification

The identification of the fauna presents one of the most difficult problems connected with faunistic surveys. A dearth of specialists in the field makes outside assistance limited. In the present studies Dr. Evans has concentrated on the Acarina (especially the Oribatidæ) which are the most numerous of soil arthropods. A large number of samples collected from various sites have yielded over 60 species of Oribatid mites. These have been identified and mounted for future reference. Dr. H. Gisin, Geneva, has kindly assisted in the identification of the Collembola.

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BEE DEPARTMENT

By C. G. Butler

As in previous years several members of the department have read papers and given demonstrations at meetings of Scientific Societies, Beekeepers' Associations and other organisations. An Extension Course, arranged by London University, on the Physiology and Behaviour of the Honeybee was also given by Dr. C. G. Butler.

During the course of the last twenty-five or thirty years, very considerable advances have been made in the study of the sense-physiology and behaviour of the honeybee. As a result, numerous papers have been published in the world's scientific journals, and the need for some comprehensive account of the senses of the honeybee and the manner in which she uses them has become increasingly apparent. An attempt has been made to fill this want by the publication of a small book giving the results of some of the work (169).

Members of the department have continued to serve on various Committees such as the Bee Disease Advisory Committee, British Standards Sub-Committee for Beekeeping Equipment and the B.B.K.A. Research Committee. A new Bulletin on beehives has also been prepared for the Ministry of Agriculture and Fisheries.

Behaviour of Honeybee in the Field

Although the sense physiology of the honeybee has been extensively investigated, notably by von Frisch and his school, relatively little work has until recently been done on the way in which these senses are employed in the field, despite the fact that a sound knowledge of foraging behaviour is an essential preliminary to the properly controlled employment of the honeybee as a pollinating agent for fruit and seed crops.

Since 1939 a great deal of attention has been given by members of the department to this problem and as a result a number of papers have been published.

In 1943 Butler, Jeffree and Kalmus (J. Exp. Biol. **20,** 65–73) published the results of some work on the behaviour of marked honeybees when seeking sugar syrup from dishes and also when collecting nectar from various kinds of flowers. A large number of dishes were used in these experiments and were regularly arranged at twenty yard intervals from one another in a meadow. The data obtained confirmed and extended the work of earlier observers and indicated that once a honeybee has discovered a rich and abundant source of syrup or nectar at a particular site she tends strongly to confine her attention to this one site for hours and sometimes days on end; in the case of a dish of syrup to one particular dish and in the case of a plant to a definite and restricted area of the crop of flowers.

It was observed, however, that although this was the general rule there was, particularly when the supply of syrup in a dish failed or when the nectar supply in a group of flowers became diminished, a tendency for some of the bees that had been visiting a given dish or group of flowers with great regularity to visit neighbouring dishes or flowers. Since, however, the general tendency was clearly for a bee to confine her attention to a definite "foraging area"

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little significance was attached at the time to the very small proportion of the total foraging population that was visiting a dish or group of flowers which strayed on to adjacent dishes or flowers. It was also found that when the bees were offered syrup of two different concentrations in dishes set out at random in a field the bees tended to congregate upon those dishes which contained the more concentrated syrup. Bees have frequently been observed at any given time to choose the species of flower which is yielding the richest nectar, and in 1945 Butler (J. Exp. Biol., **21,** 5–12), as a result of further work, reached the conclusion that nectar concentration determines in the first instance which species of plant will be visited in preference to others in flower at the same time in any given district, and that the abundance of the nectar then determines the proportion of the foraging population of a colony which will work the flowers with the richest nectar.

In 1949 Ribbands published the results of some observations on the movements of honeybees which were foraging in a specially planted garden. The bees were so marked that each individual could be readily recognised from all other individuals.

The garden contained five kinds of flowers which were arranged in long rows and large beds, and the visits of marked bees to individual flowers in this garden were very carefully noted. In one part of the garden there was a row of *Eschscholtzia* plants growing parallel to and only nine inches away from a similar row of *Limnanthes* plants. Both species were in flower at the same time and although the *Eschscholtzia* plants were taller than the *Limnanthes* plants, the flowers of both were intermingling to a considerable extent. Yet, despite the close proximity of these flowers to one another most of the bees visiting them worked one or other of them, completely ignoring the other. Two marked bees, however, were found to be working both crops, and one of these bees was watched for two consecutive days and each visit paid to each flower in the garden was recorded. At first this bee appeared to be visiting both kinds of flowers indiscriminately, later it was noted, however, that during the course of the morning the proportion of *Eschscholtzia* flowers visited per foraging trip was gradually increasing, the proportion rising from 37% on the second foraging trip of the day to 61% on the sixth trip. The process was then reversed and the proportion of *Eschscholtzia* flowers visited per trip fell rapidly and consistently, eventually falling to 0·2% on the last trip of the day. These changes in the proportion of *Eschscholtzia* and *Limnanthes* flowers visited per trip were accompanied by changes in the period of time required by this bee to collect a full load and it would appear to be likely that they resulted from changes in the relative attractiveness of the two crops.

These regular changes in the proportions of the flowers of these two species that were visited on each foraging expedition indicate that this bee was not foraging in a random manner but was making a series of definite choices, based, presumably, on her ability to appreciate changes in the relative attractiveness or food content of the flowers of these two species at different times of the day.

The increasing length of time spent by this bee on each successive foraging expedition throughout the day indicates that the *Limnanthes* flowers were becoming less and less productive, but the

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single visits paid to *Eschscholtzia* flowers every now and again indicate that at each time of sampling the *Eschscholtzia* flowers were still found to be less attractive than the *Limnanthes* flowers. Ribbands pointed out that after only a single unsatisfactory visit to an *Eschscholtzia* flower the bee returned to the *Limnanthes* flowers ; each unsatisfactory visit to an *Eschscholtzia* flower appeared to reinforce the impression created on this bee by previous unsatisfactory visits to this species, with the result that the intervals between the occasional visits made to the *Eschscholtzia* flowers grew progressively longer. It would appear as though this bee was exercising both choice and memory, and that she was continually selecting the flowers of that species which was most satisfying to her at the time. Results illustrating similar behaviour on the part of other bees working in this garden were obtained.

It appears to be reasonably certain, therefore, that honeybees do not wander over a crop of different species of flowers at random, visiting first one species and then another, but rather that they quickly become accustomed to visit one particular species and a relatively small part of the total area occupied by a crop of flowers of this species. Every now and then, however, a bee will visit experimentally a few flowers of another species growing in the vicinity possibly only the flowers of one that is growing in the immediate vicinity, and, should it prove to be a more profitable source of food than that species, or, perhaps, than those species, which she has visited hitherto, each bee will select for herself a foraging area on the crop of this new species of flower and will remain faithful to it just so long as she does not discover, during one of her experimental visits, an even more profitable source of food elsewhere.

Recently Miss G. Wykes has been attempting to determine whether the variations which are known to occur in the composition of the total sugar content of floral nectars influence the preference shown by the honeybee for the nectar of one species of flower over that of another. Equal volumes of solutions of the same concentrations, but differing in constituent sugars, were offered to bees in the field and the preferences of the visiting bees noted. It was found that at the concentration of the solutions that were offered a significant preference was shown by the bees for a solution containing sucrose, glucose and fructose in the proportions 1 : 1 : 1, in comparison with any solution of the individual sugars, or of mixtures of these sugars in various proportions. This result appears to be of some biological significance since nectar, the natural source of carbohydrate for the bee, normally consists of a mixture of these three sugars, possibly in certain cases in the proportion 1 : 1 : 1.

This investigation is being continued in the laboratory and similar results to those in the field have been obtained, but further experiments have shown that the relative sweetness to the honeybee of the various sugar solutions almost certainly varies with their concentration, as is the case in man.

During the last few year Butler has been investigating the method by which a scout bee, that is to say a bee which leaves her hive without any preconceived ideas of where she is going to seek food or with what perfume it is associated, finds a new source of food. He has found that the honeybee is attracted to any area in

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which a strong floral perfume, such as oil-of-lavender, is present, and that she then tends to seek nectar from any small crevices in any small coloured, preferably patterned and moving, object, such as a disc of coloured paper, in this area.

Once a scout bee has been led to a source of food by the presence of a strong floral perfume, followed by colour or pattern, she samples the contained food and should it prove profitable to work, that is if it is both rich and abundant enough to satisfy her, she returns to her hive, and by means of the " dance language " discovered by von Frisch, quickly recruits further bees to work the source that she has discovered.

The Effects of Anaesthetics upon Foraging Behaviour

C. R. Ribbands has continued his work on the effect of various anaesthetics upon the foraging behaviour of bees, and a paper on this subject will be published shortly (167).

He has demonstrated that anaesthesia with chloroform does not either impair the memory, influence the foraging behaviour or reduce the longevity of honeybees. On the other hand, anaesthesia with carbon dioxide, although it does not impair the memory of treated bees, does result in a permanent change in their behaviour but has no direct effect upon their longevity. The pollen collecting activities of bees treated with carbon dioxide are either eliminated altogether or very markedly reduced. Similarly the treatment of newly emerged bees with carbon dioxide results in the elimination of all or most of their brood rearing and wax secreting activities and causes them to commence to forage at an early age. Since foraging life is necessarily more hazardous than life within the hive, the expectation of life of bees that have been treated with carbon dioxide is less than that of control bees that have not been treated in this way.

The effects of anaesthesia with nitrogen are similar to those obtained with carbon dioxide. It would appear likely, therefore, that temporary oxygen lack is the factor which results in the changes of behaviour mentioned.

Attempts are being made in the laboratory to study the physiological effects of anaesthesia with carbon dioxide on honeybees, and an attempt to discover the fundamental nature of the basis of the division of labour exhibited amongst the worker bees of every colony. Little success has been achieved so far, however.

Pollen Trapping

The regular routine trapping of samples of pollen which has been carried out for several years by means of pollen traps placed on the entrance of hives containing normal colonies of bees has been discontinued for the time being.

Although this technique is undoubtedly a useful tool for the elucidation of certain specific problems it appears doubtful whether routine trapping, with the heavy labour of sorting the catch into its constituent pollen species, will yield further results of major importance unless some method can be devised to overcome some of the errors inherent in the present apparatus. The pollen traps so far devised are all of the same basic design and suffer from the serious disadvantage that they trap a higher proportion of the larger sized

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pollen loads. It is characteristic of some plant species that bees only collect very small loads of pollen from them and these loads, although they may in the aggregate be extremely important in the economy of a colony are almost entirely missed by the present traps.

J. Simpson has further elaborated his keys, based on those worked out by Miss A. D. Synge when she was a member of the department, for the identification of the pollens of British plants visited by bees. These keys are, together with the fairly extensive pollen collection, in constant use in the department and are thus being subjected to considerable testing. It was hoped that it might prove to be possible to publish a monograph on the identification of the pollens of bee plants occurring in Britain, but the heavy cost of reproduction of the necessary photomicrographs appears to make this impossible, at all events for the time being.

Bee Breeding and Strain Trials

The development of the technique of artificial insemination of queen honeybees has been continued, and certain small advances have been made. Much work still requires to be done on the study of the sexual development of drones, however.

Between June 9th and August 20th, 191 queens were inseminated and, on account of various accidents such as the destruction of a large batch of queens early in the season by overheating with a microscope lamp, less than 50 per cent were wholly successful. None the less 43 queens of various strains which it was desired to test were introduced into colonies in out-apiaries and continued to lay well and produce satisfactory brood. The development and behaviour of these colonies will be studied in detail during 1950.

During 1949 the development and behaviour of the inseminated queens of different strains introduced in the summer of 1948 into nuclei in one of the out-apiaries was studied and some useful information obtained. Some of the colonies headed by these queens did remarkably well, and the difference observed between the different strains of bees in the apiary was well marked.

Work has been commenced in an attempt to distinguish biometrically between the different strains of bees maintained by the department. Since the production by means of instrumental insemination of the large number of queens necessary for strain trials is an extremely tedious business, it is hoped that it will prove to be practicable to mate large numbers of queens with selected drones in normal queen-mating apiaries and, by studying the biometrical ratios of the offspring of queens mated in this way, to be able to select those queens that have mated with the drones desired.

Instrumental insemination will, of course, continue to be employed for the production of breeder queens.

Nectar Secretion

Miss G. Wykes has continued her work on the influence of the available supplies of carbohydrates on the process of nectar secretion by various flowering plants. By placing flowers of the same age in feeding solutions of varying sucrose content she has found that with increasing concentration of the feeding solution, up to about 20 per cent., there is a proportionate increase in the concentration of the nectar secreted by the flower and in the total amount of sugar

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secreted. No significant differences were observed when the feeding solutions consisted of glucose, fructose or sucrose of the same concentration. By means of ringing and defoliating experiments with the flowering shoots of horse-chestnut and apple trees it was shown that interference with the normal carbohydrate supply either before or during the flowering period, results in a partial reduction, or total cessation, of nectar secretion.

An attempt has also been made to determine the possible effects of insect visits on nectar secretion. Preliminary results suggest that frequent withdrawal of nectar from a flower by insects tends to stimulate the secretion of further nectar.

Syrup Feeding

J. Simpson is investigating the composition of the stores of "honey" resulting from the autumn feeding of sugar syrup to colonies of bees. A few analyses undertaken in 1948, and the results so far obtained in the examination of a more extensive series of samples resulting from 1949 feeding, have shown that "honey" produced from autumn fed sugar syrup has a somewhat lower water content, and a very much higher sucrose content than normal floral honey. These results were obtained when both concentrated and dilute syrup was fed and whether feeding took place early or late in the season.

Humidity in the Winter Cluster

J. Simpson has now completed a paper on the humidity of the atmosphere within a winter cluster of honeybees (169), and has found that variations in the atmospheric conditions outside the hive have little effect at normal winter temperatures on humidity within the cluster. He has also continued his previous work on the water balance of the individual honeybee by making use of Dixon's constant pressure modification of the Barcroft respiratory manometer to measure the loss of water by individual bees.

It is felt that the results so far obtained require confirmation by other methods, but they suggest that bees are unable to compensate for variations in atmospheric humidity by control of the evaporation of water from their bodies, and that when a honeybee is in a state of rest very little of the water lost passes through the spiracles.

Nosema and Amoeba Diseases

H. Hassanein has continued his work on the development of these diseases in the adult honeybee and on their influence upon the behaviour of infected individuals.

European Foul Brood Disease

Mrs. Schreiner (Miss E. Kops) has continued her attempts to repeat the observations of Professor R. Burri of the Liebefeld Institute, Berne, on the *Bacillus eurydice, Bacillus alvei, Bacillus pluton* complex. So far no results similar to those reported by Professor Burri have been obtained and in no case so far has *B. pluton* been recognised in a pure culture of *B. eurydice*.

(This work, since Miss Kops' marriage, has been transferred to Cambridge for the time being.)

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INSECTICIDES AND FUNGICIDES DEPARTMENT

By C. Potter

The only change in the scientific staff of the department consisted of the appointment of Mr. P. Burt as research entomologist. During the course of the year Mr. A. H. McIntosh was awarded the Ph.D. degree of London University.

The lack of accommodation and in particular lack of facilities for providing controlled environments was felt even more severely than in previous years, but deficiencies in equipment, have, to a very large extent, been remedied.

The central theme of work of the department continues to be the laboratory study of the factors that affect the susceptibility of insects to insecticides. In addition some special studies have been undertaken and some field experiments carried out.

Chemical

Analytical chemistry

Rotenone. During the year a series of analyses were made on a sample sent in by the Board of Greenkeeping Research.

Pyrethrum. (a) World wide collaborative analysis of pyrethrum flowers. Assistance was given by the department in the preparation of a report on this subject, based on the work carried out in the previous years. (b) Colour reaction. It was observed that a colour reaction of carboxylic acid derivatives was also applicable to the pyrethrins.

Hexaethyl tetraphosphate. Estimations of the tetraethyl pyrophosphate content of samples of hexaethyl tetraphosphate were carried out using the method of Jacobson and Hall as modified by Albright and Wilson to avoid interference due to added materials.

Physical chemistry

The effect of particle size of suspensions of contact insecticides on their toxicity as contact poisons. This work has been continued mainly in order to try to explain why D.D.T. in the form of large crystals is easily taken up through the insect cuticle and crystalline rotenone, under the same conditions is not.

It is supposed either that D.D.T. is considerably more soluble than rotenone in the outermost (wax) layer of the insect epicuticle or that the critical particle size, under which solubility becomes greater than normal, is different for D.D.T. in wax than for rotenone in wax. On this basis it would be expected that at a low temperature after treatment, small particles of D.D.T. would be more toxic, relative to large, than at a higher temperature after treatment.

Experiments have been carried out which show that this is so. D.D.T. needles (350μ) are about five times as toxic to adult *Tribolium castaneum* Hbst. as D.D.T. colloid when the insects are kept at 25°C. after treatment, but at 11°C. the colloid is about twice as toxic as the needles. With adults *Oryzaephilus surinamensis* L. as test subjects the results are more marked. Part of this work has been published. Further experiments along these lines are contemplated.

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Surface active agents. The work started in 1946 on the effect of surface active agents on the behaviour of chemicals applied as contact insecticides in aqueous medium is being continued. No consistent large differences in the toxicity of the insecticide due to different surface active agents has as yet been found, but differences up to three or four times may occur. Differences in the surface active agent used may affect considerably the physical state of the deposit of insecticide. This work is being continued.

Biochemical

The survey of the effects of insecticides on the oxygen uptake of insects has been continued and a paper describing the experimental technique devised and some of the results obtained has been accepted for publication.

Preliminary work on insect esterases has been carried out, and extracts of the mealworm *Tenebrio molitor* both adults and larvæ, and of the flour beetle, *Tribolium castaneum* Hbst. adults have been shown to hydrolyse rapidly ethyl butyrate and o-nitrophenyl acetate. Extracts of adult *T. castaneum* did not appear to show any activity in the hydrolysis of acetyl choline.

Some work has been done on the capacity of organo-phosphorus compounds used as insecticides to inhibit the activity of these insect esterases. The hydrolysis of o-nitrophenyl acetate is inhibited by E. 605 (O.O. diethyl-o-p-nitrophenyl thionophosphate) and H.E.T.P. (Hexaethyl tetraphosphate). At pH 6·5 and 25°C. the concentration required to give 50 per cent. inhibition is approximately 10^{-7} M for E. 605 and 10^{-8} M for H.E.T.P. when estimated on the basis of the presumed active constituent—tetraethyl pyrophosphate. An attempt is being made to integrate this work on the mechanism of action of poisons with that on bioassay methods as outlined in the section on bioassay. It is proposed to continue the work both on the effect of poisons on the oxygen uptake of insects and on insect enzyme systems.

Synthetic organic chemistry

Work is proceeding on the synthesis and reactions of keto-alcohols related to the pyrethrins.

The aim of the work under this heading is the study of the relationship between molecular constitution and configuration and insecticidal activity. The work is at present confined to the pyrethrins. Contact has been established with Dr. F. B. LaForge in the Bureau of Entomology and Plant Quarantine, U.S.A., and collaboration established with Dr. S. H. Harper in England. An account of a toxicity study of two compounds closely related to the pyrethrins obtained by the courtesy of Dr. LaForge is given in the bioassay section.

Bioassay

Organo-phosphorus compounds

Insecticidal activity of E. 605, T.E.P.P. and H.E.T.P. Following up work done in the previous year additional laboratory tests of insecticidal activity of samples of E. 605 (O.O. diethyl O.p. nitrophenyl thionophosphate), H.E.T.P. (Hexaethyl tetraphosphate) and T.E.P.P. (Tetraethyl pyrophosphate) were carried out.

The materials were tested for their effect both as contact and

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stomach poisons and some preliminary experiments made on their ovicidal effect.

Contact effects

Larvæ of *Plutella maculipennis Curt.* (Diamond back moth), E. 605 (M.L.D. 0·0055% w/v) was approximately six times as toxic as T.E.P.P. (40% Tetraethyl pyrophosphate) (M.L.D. 0·035% w/v). When measured at LD50 level, D.D.T. (M.L.D. 0·00386% w/v) was slightly more toxic than the E. 605.

Adults of *Phaedon cochleariae* (Mustard Beetle). E. 605 (M.L.D. 0·00615% w/v) was twenty-five times as toxic as T.E.P.P. (40% Tetraethyl pyrophosphate) (M.L.D. 0·0153% w/v) measured at LD50 level.

The T.E.P.P. was approximately sixteen times as toxic as nicotine (M.L.D. 0·234% w/v).

Adults of *Tribolium castaneum* Hbst. (Flour Beetle). E. 605 (M.L.D. 0·000775% w/v) was twenty seven times as toxic as T.E.P.P. (40% Tetraethyl pyrophosphate) (M.L.D. 0·0211% w/v) forty four times as toxic as H.E.T.P. (15% Tetraethyl pyrophosphate) (M.L.D. 0·0342% w/v).

Stomach poison effects

Strips of food leaf bearing known doses of insecticides were fed to the last instar larvæ of *Diataraxia oleracea* (Tomato moth).

The figures for the M.L.D. were taken from the provisional probit lines and were estimated in terms of mg. per larva, the larvæ being approximately 0·4 gm. each.

E. 605 (commercial sample) 0·0035–0·0045 mg., T.E.P.P. (75% Tetraethyl pyrophosphate) 0·070 mg., lead arsenate (99% pure) 0·075–0·090 mg., D.D.T. (pure p.p. 'isomer) 0·012 mg. Thus E. 605 was the most toxic, being approximately three times as toxic as D.D.T. and about twenty times as toxic as T.E.P.P. and lead arsenate.

Ovicidal effects

Preliminary tests were carried out with E. 605 and T.E.P.P. on the eggs of *Diataraxia eleracea* (Tomato moth), *Plutella maculipennis* (Diamond back moth) and *Oligonychus ulmi* (Fruit tree red spider).

E. 605 showed high ovicidal effect to the lepidopterous eggs at concentrations from 0·1% w/v to 0·01% w/v but the T.E.P.P. showed little or no toxicity at the same concentrations. Variable results were obtained with E. 605 on the red spider eggs, in one test it appeared to be less toxic than D.N.O.C. at 0·1% w/v. T.E.P.P. showed no action until the concentrations were raised to 0·8% w/v when there was some evidence of toxicity.

Relationship between the tretaethyl pyrophosphate content of H.E.T.P. and its insecticidal and anti-esterase activity

It has been stated that the insecticidal activity of H.E.T.P. is entirely due to tetraethyl pyrophosphate present in it. A series of samples of H.E.T.P. were received from Messrs. Albright and Wilson, with a request that their insecticidal activity should be investigated. It was decided to carry out this work and at the same time to determine what correlation, if any, there was between the insecticidal activity of the samples, their content of tetraethyl pyrophosphate and their capacity to inhibit the esterase activity. The esterase was

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obtained from larvæ of the mealworm (*Tenebrio molitor*).

It is proposed to do some more work on this subject and to publish a full account later.

From the figures already obtained it would appear that while the tetraethyl pyrophosphate content gives some indication of both insecticidal activity and of anti-esterase activity, other active components are present in the mixtures.

The possibility of using anti-esterase activity as a method for the estimation of insecticidal potency of samples of organo-phosphorus compounds of similar constitution is under consideration.

N Isobutylamides

At the request of the Agricultural Research Council three amides of structures related to that proposed for Herculin (an insecticidal material isolated from prickly ash bark) which had been synthesized by Drs. Raphael and Sondheimer (Nature, 1949, **164,** 707) were tested for their activity as contact insecticides.

Materials

A. $C_3H_7CH\overset{cis}{=}CH(CH_2)_4CH\overset{cis}{=}CO.NH.CH_2.CH<\begin{matrix}CH_3\\CH_3\end{matrix}$

B. $C_3H_7CH\overset{cis}{=}CH(CH_2)_4\ C\equiv CO.NH.CH_2.CH<\begin{matrix}CH_3\\CH_3\end{matrix}$

C. $C_3H_7C\ =\ C(CH_2)_4\ C=CO.NH.CH_2CH\ <\begin{matrix}CH_3\\CH_3\end{matrix}$

The materials were tested on apterous, viviparous, parthenogenetic females of *Macrosiphum solanifolii* (potato aphid), fully grown larvæ of *Plutella maculipennis* (diamond back moth), and adult *Phaedon cochleariæ* (mustard beetle). None of the materials showed any appreciable toxicity at concentrations ranging from 0·5%–0·005% w/v when applied in aqeous medium containing 10% w/v acteone and 0·1% w/v sulphonated lorol.

Synthetic compounds allied to the pyrethrins

The announcement by Dr. LaForge and his colleagues of the synthesis of highly active esters of similar constitution to the pyrethrins was of special interest to us, since work was in progress in the department on the relationship between the chemical structure and biological activity of the pyrethrins and similar molecules.

By the kindness of Dr. LaForge and of the Chemical Biological Co-ordination Committee of the National Research Council of America, we obtained samples of the esters of (±)–3–methyl–2–allyl–cyclopent–2–ene–4–ol–1–one with the natural (+)–trans– and the synthetic (±)–cis–trans–chrysanthemum monocarboxylic acids.

The toxicity of these two esters as contact insecticides was compared with that of an extract of pyrethrum flowers to four insect species. It was found that both the absolute and relative toxicity of the materials varied with the species of insect used. The compound with the natural acid and synthetic alcohol varied from about four times the toxicity of the natural pyrethrins to the larvæ of the diamond back moth (*Plutella maculipennis*), to about one eight as

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toxic to the adult apterous viviparous females of the potato aphid (*Macrosiphum solanifolii* Ashm.). The fully synthetic material varied from approximately twice as toxic as the natural pyrethrins—test subject, *Plutella maculipennis* Curt., to approximately one sixteenth as toxic—test subject *Macrosiphum solanifolii*.

This variation in relative toxicity with the species of insect used as test subject is interesting since the compounds are chemically closely related. The variation in relative toxicity with test subject is further illustrated since the ester with the natural acid is approximately as twice as toxic as the ester with the synthetic acid to three of the test subjects, but was about 4/5 as toxic to the fourth. These specific variations render the task of relating molecular structure and configuration to toxicity difficult.

Biological

Bioassay techniques

A micropipette has been constructed for the injection of small quantities of insecticide into the body cavity of insects. The design of the pipette is based on the Gilmont ultra-microburette and the Heal and Menusan injection pipette. A mechanical manipulator for holding and positioning the insect for injection has also been built, to work in conjunction with the pipette. No other apparatus for precision injection has so far been described, and, in addition to its use for the study of the action of insecticides, it is proposed to study the various factors involved in injection techniques which influence the results of the experiments.

During the course of the year some advances have been made in the decision of the atomizing nozzle and other parts of the Potter spray tower. Some work has also been done on the relative importance of the direct contact effect on the body of the insect and the residual film effect using this technique normally employed with this instrument. In general the results are an estimate of the sum of the two effects. It appears that, in some instances, at least, an exposure to the film alone gives a higher toxicity than direct contact on the body of the insect alone.

The effect of stage development on resistance

Using the tomato moth (*Diataraxia oleracea*), the mealworm (*Tenebrio molitor*), and the cockroach. (*Periplaneta americana*) with D.D.T. and pyrethrum as insecticides, a study has been made of how resistance varies with the stage of development. Large differences in resistance, between different instars of a given species have been found, and even within a given instar these differences may be considerable.

Persistence of insecticides on foliage

Work on this subject has been in progress in the department for some time and has now been intensified at the request of the Colonial Insecticides Committee, which is providing additional finance.

Preliminary experiments on the persistence of D.D.T. on foliage which were carried out during previous years has been followed up in greater detail in 1949. Using turnip and cabbage foliage and a number of different formulations it was found that the type of foliage (sp. of plant) and the nature of the spray medium have a considerable effect on the toxicity of residual films of D.D.T. Using

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D.D.T. in simple crystalline suspension it was shown that on cabbage leaves the residual films rapidly lose their effectiveness as a result of attenuation of the deposit due to plant growth. Under these conditions loss of D.D.T. due to sunlight and rainfall is of negligible importance. It was found, however, that within two days after treatment and before a significant amount of leaf growth had taken place noticeable changes had taken place in the effectiveness of the deposits. There was a reduction in toxicity to insects which only walk the surface but do not eat the leaf and an increase in toxicity to insects that eat the leaf as well as walking the surface. Chemical analyses showed that over a period of one month there was no loss of D.D.T. films on cabbage provided the plants were not exposed to rainfall or to short wave ultra violet light.

Natural fluctuation in the resistance of insect populations and effect of host plant on resistance

Very little work was done on these subjects owing to difficulties with the aphid, mainly due to attacks by parasites and fungal disease.

Mechanism of selection of resistant strains of insect

Some work preparatory to a study of this subject has been carried out. Selected strains of *Drosophila melanogaster* are being reared of known genetical constitution. Spraying techniques for use with these insects are being elaborated and methods for the permanent preparation of individual specimens have been studied so that any differences that occur before and after treatment may be compared.

Effect of environment on the toxicity of contact insecticides

Work on this subject is being continued.

Insect rearing

The twenty five insect species listed in the 1948 report have all been reared during the present year. In addition stocks of *Locusta migratoria* (African migratory locust) and *Pionea forficalis* (Garden pebble moth) have also been reared. A particular study has been made of the biology of *Diataraxia oleracea* L. (Tomato moth) and *Phaedon cochleariæ* F. (Mustard beetle), which have proved to be among the most satisfactory test subjects.

A great deal of trouble has been experienced during the current year with the aphid stocks due to parasites and fungus disease and probably other factors. It has not so far been possible to work on improvements of the rearing technique but this will be done as opportunity offers.

Studies on insect diapause

Some work has been done on the factors influencing the diapause in mustard beetle and tomato moth since this is a major factor when considering rearing techniques.

The mustard beetle overwinters as a resting adult. This can be activated and induced to oviposit within a few days by placing it in a temperature of 30°C. At 12–24°C. activation does not occur or is delayed unless the insect is subjected to 16 hours light per 24 hours. It was found with tomato moth that climatic conditions during the larval instar alone are responsible for inducing or preventing diapause in the pupa. Sixteen hours light per 24 hours prevents diapause

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except at low temperatures (12°C.). Eight hours light per 24 hours induced diapause except at high temperatures (34°C.).

Field Experiments

Control of wireworms

The experiment started in the autumn of 1947 was continued in order to study the residual effects of the various treatments. In addition, a part of the experimental area was set aside for testing possible tainting effects, resulting from the treatments with benzene hexachloride. Judging on crop yields it was found that the autumn 1947 treatments of benzene hexachloride (12–14% gamma isomer) broadcast at 7·9 lb. crude B.H.C./acre, benzene hexachloride drilled with the seed at 2·9 lb. crude B.H.C./acre and D.D.T. drilled with the seed at the rate of 7·2 lb./acre had the greatest residual effect, with yields of 39·6, 37·3 and 36·4 cwt./acre respectively in 1949. The soil fumigants ethylene dibromide and D.D. had less residual effect, applications of 45·5 lb./acre of ethylene dibromide and 120 lb./acre of D.D. in 1947 giving yields of 34·1 and 31·8 cwt./acre in 1949. Seed treatment had no residual effect. The control yield was 28·4 cwt./acre. Taking into account the previous year's results it would appear therefore, that the treatment where benzene hexachloride was drilled with the seed and broadcast gave good immediate results and good residual effects, ethylene dibromide and to a lesser extent D.D. gave good immediate results and fair residual effects, seed dressing with high gamma isomer B.H.C. gave good immediate effects and no residual effects and D.D.T. gave poor immediate effects but good residual effects. Evidence was obtained that there was a risk of taint occurring in root crops planted in soil previously treated with crude Benzene hexachloride at dosages from 0·98–5·92 lb./acre.

Control of flea beetle

A large scale experiment on the use of benzene hexachloride, D.D.T. and E. 605 to control flea beetles failed owing to lack of attack, but small scale trials indicated that benzene hexachloride sown with the seed might give good protection. It is hoped to follow up this work.

Control of aphids carrying virus on potatoes

In collaboration with the Plant Pathology department a preliminary experiment was carried out on the control of aphids carrying virus in potatoes. The results of this experiment are not yet available.

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FIELD EXPERIMENTS

By the Plot Committee

Field Experiments at Rothamsted and Woburn

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

The number of plots handled by the Field Staff at Rothamsted and Woburn were as follows :—

	Grain	Roots	Hay	Grazing	Total
Classical Experiments					
Rothamsted ..	121	72	47	—	240
Woburn	24	—	—	—	24
Modern Long-Term Experiments					
Rothamsted ..	279	232	84	32	627
Woburn	149	218	31	12	410
Annual Experiments					
Rothamsted ..	489	208	12	—	709
Woburn	—	—	—	—	—
Total					
Rothamsted ..	889	512	143	32	1,576
Woburn	173	218	31	12	434
Grand Total ...	1,062	730	174	44	2,010

Note : Grain includes cereals, beans, peas, linseed. Roots include potatoes, sugar beet, mangolds, cabbage, leeks. Hay includes lucerne and cut grass.

One experiment of 40 plots on winter beans on Stackyard Field could not be drilled owing to the wet state of the ground in late autumn and was abandoned, so the number of plots actually harvested on the two farms was 1970.

The season 1949 was remarkably dry, mild and bright. Every month from January to September inclusive was below the average in rainfall, and there had been no excess of rain at the end of 1948. There was very little severe frost in the winter, and practically no snow. The characteristics of the season and the effects of the weather on crops are fully described in the section of this report dealing with the Rothamsted and Woburn farms.

In the year under review the classical and long-period experiments were continued. Most of them have already been summarised in recent Reports.

Ley Arable Experiment, Rothamsted

The general purpose and the scheme of treatments of the new ley arable experiments at Rothamsted were given in the Report for 1948, p.98.

The first year of this elaborate and exacting experiment has been used in developing the technique. Wheat was grown on two blocks on Highfield and two on Fosters. On Highfield where the wheat was drilled on recently ploughed old turf, the plant came well but went off badly during the winter and looked very poor indeed at the turn of the year. Later earth nut (*Conopodium denudatum*) appeared as a

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serious weed in the crop and was considerably reduced by dusting with M.C.P.A. weedkiller. The crop then improved a little and yielded 15·6 cwt. grain per acre. There were no visible effects due to the different levels of nitrochalk on the sub-plots. On Fosters the wheat was earlier sown and looked distinctly better, the effect of added nitrogen was also slightly greater than on Highfield. The mean yield was 23·3 cwt.

All leys and legumes were sown in the open ground in the spring of 1949. Conditions were by no means ideal as the seedbeds were very dry ; nevertheless the take was reasonably good, with lucerne as the best-looking patches on both fields, though some of the leys and reseeded grass (identical at this stage) looked fresh and covered the ground well. As the dry weather persisted in early summer all young sowings had a great struggle with strong-growing weeds, thistles on Highfield, " knotgrass " (*Polygonum aviculare*) on Fosters. The " knotgrass " dominated the leys so badly in early autumn that the plots were sprayed with sulphuric acid which clearly shifted the balance in favour of the grass.

Grazing by sheep was reduced by the very dry weather to only two rounds per plot in 1949, and the established grass land in Highfield did no better than the new stands. There were two cuts of cut grass on Highfield, but only one on Fosters. Lucerne gave one light cut on each field. By late summer everything except the lucerne was badly burnt up. The season was used to develop a grazing technique. Temporary post and netting fences were tried but did not hold the stock, particularly when an enclosure was grazed right down and the animals were hungry. These fences will be replaced in future by wheeled iron hurdles, a type that has been used successfully at Woburn for a similar purpose.

Spring-sown Cereals

For the past three seasons four kinds of cereal crops have been compared for spring sowing. The experiments were located in a different field each year. The crops were : Star oats, Atle wheat, Bersee wheat, and Plumage Archer barley. All crops were tested at several nitrogen levels, sulphate of ammonia being applied at 0, 0·3, 0·6, 0·9 cwt. N. per acre. Superphosphate and muriate of potash were also tested. The mean results over the three years were as follows :—

Mean Yields and Responses: cwt. per acre 1947-49

Fertilizers	Grain				Straw			
	Oats	Atle	Bersee	Barley	Oats	Atle	Bersee	Barley
0·0 cwt. N	16·4	18·6	19·2	23·5	33·2	28·4	27·5	25·5
0·3 ,, ,, ...	20·9	21·5	23·8	27·3	38·9	34·2	34·4	31·1
0·6 ,, ,, ...	22·3	23·0	24·3	28·4	39·2	37·9	38·9	35·0
0·9 ,, ,, ...	23·3	22·8	25·3	27·7	40·7	38·7	40·8	36·0
Mean	20·7	21·4	23·2	26·7	36·0	34·8	35·4	31·9
Response to Superphosphate ..	1·6	—0·6	—0·3	0·8	0·4	0·1	0·3	0·8
Response to Muriate of Potash ..	—0·3	—0·4	1·2	1·8	—0·6	0·4	—0·1	1·2

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In grain production barley stands well above the other spring-sown cereals at all levels of nitrogenous manuring. On the average oats and Atle wheat each yielded 6 cwt. less than barley, and spring sown Bersee wheat about 3½ cwt. less. In these three experiments Bersee wheat sown in the spring gave somewhat higher yield than Atle though it was later to ripen. All the cereals responded well to nitrogenous dressing, but all showed a marked falling off in response at the higher levels. Thus the first 1½ cwt. of sulphate of ammonia produced a mean increase over all crops of 4 cwt. of grain. When the dressing of sulphate of ammonia was raised to 3 cwt. per acre the further increase was only 1 cwt. grain while 4½ cwt. of sulphate of ammonia gave practically the same yield as 3 cwt. There was no very marked difference between the behaviour of the different crops in their responses to nitrogen, oats were perhaps slightly more responsive than barley at all levels; the wheats being intermediate. The level of yield and responses to nitrogen varied with the season, in particular in the abnormally dry season 1949 the nitrogen responses were lower than in the other two more favourable years.

The responses to phosphate and potash were much smaller than to nitrogen. Oats gave significant responses to phosphate in two years out of the three; the yield of Bersee wheat and barley was slightly increased by potash.

The nitrogen responses in the straw were larger than the corresponding grain responses, and though they fell off somewhat at the higher levels they showed less curvature. In the moist season 1948 oats and barley produced about 6 cwt. more straw and wheat from 12-17 cwt. per acre more than in the dry years. In wheat and barley the responses to nitrogen were bigger and more sustained in the wet season than in the dry ones. Phosphate and potash had very little effect on straw yield. The biggest increase, 1·2 cwt. per acre, was produced by muriate of potash in the straw of barley.

The Annual Experiments of 1949

The following brief notes deal with the main points arising from those annual experiments of 1949 which do not belong to larger series of experiments or are not reported elsewhere by the departments specially concerned.

Potatoes

There were three annual experiments on potatoes:—(1) Four levels of farmyard manure applied in three different ways, in presence and absence of each of the three main nutrients, N, P, K. This experiment was carried out on Sawyers III. The dressings of dung were 0, 5, 10, and 15 tons per acre and these were applied either ploughed-in in winter, or ploughed-in in spring, or spread in the ridges in spring. The whole experimental area was ploughed both for the winter and for the spring application. The potatoes without dung gave 5½ tons of potatoes; on the average of all methods of application dung increased the crop by ½ ton for each 5 tons applied, the effect being practically linear up to the maximum dressing. The three methods of application give closely similar results on the average of all rates. Since no adjustment was made

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for loss during storage the spring applications were derived from rather heavier amounts of dung than were actually applied in the winter dressings. A fuller examination of this experiment will be made when the response curves are available for each method of application. Potash was the most effective supplementary nutrient in the absence of dung but the responses were steadily reduced almost to zero as the dressings of dung were increased. Nitrogen gave good effects even in the presence of dung. (2) Time of planting experiment, Sawyers III. This has now been tested on a different field each year for several seasons. The earliest planting on March 29th gave a yield of 5·4 tons which fell to 4·5 tons for the latest planting on May 30th, the other plantings being intermediate in yield. Dung gave a response of 2 tons per acre which was practically independent of the date of planting the potatoes. Nitrogen with a mean increase of 0·7 tons and potash with a mean increase of 0·5 tons were distinctly more effective on the earliest planting than on the rest. As usual there was a negative interaction between dung and potash. The above experiment was used by the Plant Pathology Department for observations on the spread of virus diseases and will be more fully reported by them. (3) Methods of planting potatoes, Great Knott III. Arising out of the remarkably rapid increase in the mechanical planting of potatoes, a start was made in 1949 in testing different methods of placing the tubers and applying the fertilizers. The standard method of applying fertilizers down the ridges followed by hand planting gave significantly lower average yields than planting by the dropper either on the flat or in the ridges. The seed was infected with 'dry rot' and although it was carefully sorted it is possible that some diseased tubers were planted. The loss of plant due to this cause would probably be more severe on the dried-out open ridges which were hand-planted than on either of the other methods where the sets were put straight into moist soil. Fertilizer application at 8 or 16 cwt. per acre gave very small increments in yield in this experiment so the comparison of different methods of incorporating the artificials led to no clear results. The experiment will be repeated for several seasons.

Linseed. Great Knott I. An experiment was put down to test combine drilling of PK fertilizer against the same fertilizer broadcast. The material was used in granular and also in powder form, each at single and double rates per acre. Sulphate of ammonia was also tested. The plant was good and even but the plots were badly infected with Fat Hen early in the summer. This was well controlled by spraying with liquid "Agroxone" but the yield of the crop was probably reduced by weediness and drought so that finally poor yields of only about 4 cwt. of seed per acre were obtained. Under these circumstances the only definite result was a reduction of yield when the heavy dressing of fertilizer was put in with the combine drill. Thus 6 cwt. of fertilizer broadcast gave 4·5 cwt. grain and 7·9 cwt. of straw; if drilled-in the yields were only 3·3 cwt. grain and 4·9 cwt. straw. There was no certain difference between powder and granular fertilizer.

Spring bean varieties

Four Dutch varieties of spring beans were compared with five English and Scottish strains at three seed rates (1, 1½, and 2 units).

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The rates were calculated to provide equal numbers of seeds per acre. This involved seedings by weight varying from 0·8 to 2·5 cwt. per acre at the lowest rate. Yields of all varieties were light. They ranged from 5·3 cwt. for a Dutch Pigeon bean to 12·5 cwt. for an Essex strain of horse bean. The English strains from the National Institute of Agricultural Botany, and a strain of Scotch Mazagan bean gave higher yields than the Dutch horse beans, particularly at the lower seed rates. Practically all varieties gave profitable increases for increased seed rates in the sense that the increase in grain yield was usually about twice the weight of the extra seed sown. One Dutch variety of Broad beans with very large seeds failed to justify the heavier seed rates.

Other experiments

In addition to the above experiments, the following were conducted either as part of a series or specially for departments who will report the results elsewhere. (1) Placement experiments on threshed peas and spring beans. Broadcast application of PK fertilizer at several rates compared with fertilizer placed by a special experimental drill (2) Experiments on wheat, Little Knott. Agricultural conditions affecting the incidence of eyespot disease. Tests of seed rate, level of and time of application of nitrogen top dressing, sulphuric acid spraying. (Plant Pathology Department.) (3) Experiments on wheat, Little Hoos. Control of wireworm by soil fumigants. Residual effects of fumigation treatments applied to wheat in autumn 1947 (Insecticides Department).

EXHAUSTION LAND, HOOSFIELD.

The exhaustion land consists of two acres in Hoosfield lying between the acre devoted to alternate wheat and fallow and the Long Hoos boundary. Since the early continuous experiments on potatoes were terminated in 1901 this land carried a series of corn crops, either unmanured or with nitrogen only. For many years the yields of grain and straw were measured on all the old potato plots, but this was allowed to lapse after the first world war. Nevertheless the cereals still showed small but quite noticeable residual effects in the spring associated with certain of the former treatments. These residues had attracted little attention in recent years, but in the very dry spring of 1949 the crop of barley showed such remarkable differences from plot to plot that a fresh examination of the site and crops was clearly necessary.

Soon after the barley germinated it was apparent that the young plants on those parts of the field where the former experimental potatoes had received either no manure or nitrogen only were in a miserable condition. They were stunted with dull greyish leaves carrying purplish markings, showing in fact all the symptoms of acute phosphate deficiency. The sites of the old dung plots and plots that had received a long series of superphosphate dressings for the potatoes carried normal plants. The effect was so striking that the Chemistry Department set on foot an intensive sampling of crops and soil. Air photographs taken on May 13th showed the differences in ground cover very clearly. A month later the worst leaf symptoms of phosphate deficiency had disappeared, but big differences in development and maturity remained. The old plots were cut

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out and harvested separately, and chemical work on the grain and straw samples will shortly be put in hand. Arising out of the renewed interest in this piece of land it was thought desirable to put on record as much of its previous history as could be ascertained from old records.

The first mention of this area of the Rothamsted farm appears in 1856 in a paper by Lawes and Gilbert dealing with a system of growing wheat advocated by the Rev. S. Smith of Lois Weedon in Northamptonshire. The plan was to grow wheat year after year in the same field, the land being subdivided into alternate narrow strips of crop and fallow. The crop of one year stood on the fallow ground of the year before. The wheat was unmanured and deep cultivation was practised. This experiment began in 1851 and continued till 1855. From 1856-1874 this land carried a succession of wheat crops in a fertilizer experiment on four plots rather on the lines of Broadbalk. The annual treatments for wheat were: (1) complete minerals, (2) nitrogen and minerals, (3) nitrogen only, (4) no manure. The yield of these plots for the first 8 year period appear in the Journal of the Royal Agricultural Society of England, 1864, vol. 25, where they were compared with the corresponding yields of Broadbalk. The figures for the whole 19 years are in the Rothamsted archives.

In 1876 the fertilizer experiment on continuous potatoes began on the same plots and the treatments were so arranged that all four previous treatments for wheat were carried through into the potatoes on the same land. Additional treatments for potatoes were obtained by halving the original wheat plots.

The potato experiment continued until the crop of 1901 after which the land carried a series of cereal crops, usually barley, without manure of any kind. Yields were taken yearly till 1922, when cereal cropping continued without fertilizer but the crops were not weighed. Even at that period the residual effects of the dung and phosphate treatments in barley were still plainly visible, particularly in certain seasons. In 1940, it was decided to give generous basal dressings of sulphate of ammonia only, and since then the cereals have received about 3 cwt. nitrogenous fertilizer per acre yearly. It was in the presence of $2\frac{1}{4}$ cwt. of sulphate of ammonia that the barley of 1949 showed the remarkable residual effects previously described.

Irrigation of Sugar Beet

Two experiments were carried out in 1949, one on Mr. F. A. Secrett's farm at Milford, where experiments had been in progress for the previous two seasons, and the other on the land of Messrs. W. O. and P. O. Jolly at Kesgrave, near Ipswich. Both soils were light and free draining and both farmers practised overhead irrigation on commercial vegetable crops.

The summer was even drier than the very dry year 1947, and in great contrast to the wet summer of 1948 when irrigations had no effect. The following table shows the monthly rainfall at both centres during the summer months.

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Summer Rainfall, inches

	Milford			Kesgrave
	1947	1948	1949	1949
May	1·67	2·06	2·21	1·99
June	2·14	2·60	0·45	0·42
July	1·06	0·96	0·73	0·72
August	0·52	4·02	0·96	1·54
Total	5·39	9·64	4·35	4·67

At Milford the experiment was a 6 × 6 Latin Square with the following treatments on the main plots:

1 and 2	No water (O)
3	Full irrigation as directed by farmer (F)
4	As 3, with Chilean potash nitrate in irrigation water (FS)
5	Restricted irrigation, based on weather data (R)
6	Restricted to a lower level, based on weather data (M)

All plots received a basal fertilizer dressing supplying 0·42 cwt. N, 0·68 cwt. P_2O_5, and 0·89 cwt. K_2O with 5½ cwt. salt per acre.

Within each main plot 4 levels of nitrochalk were tested:—

(a)	No extra nitrochalk	Total N 0·4 cwt. N
(b)	2 cwt. nitrochalk	,, ,, 0·7 ,, ,,
(c)	4 ,, ,,	,, ,, 1·0 ,, ,,
(d)	6 ,, ,,	,, ,, 1·3 ,, ,,

At Kesgrave the general arrangements were similar but the experiment was smaller and simpler; being 4 randomized blocks of 3 main plots, each split for three levels of nitrochalk.

Main plots:—1. No water (O)
2. Watering as directed by farmer (J)
3. Watering based on climatic data (M)

All plots received 0·43 cwt. N, 1·07 cwt. P_2O_5, 0·86 cwt. K_2O, and 3½ cwt. salt.

Sub-plots:—	(a)	No extra nitrochalk	Total N 0·4 cwt. N
	(b)	3 cwt. nitrochalk	,, ,, 0·85 ,, ,,
	(c)	6 ,, ,,	,, ,, 1·30 ,, ,,

The crop at Milford was grown on narrow rows of 17 inches and closely singled, to give a very high plant population of 37,000. Unfortunately an extremely early and severe attack of virus yellows occurred. All plants were infected by the end of June and there is no doubt that the yield was seriously reduced. At Kesgrave a good commercial plant of 26,000 was secured. The virus yellows attack commenced about a month later than at Milford, and although the crop was damaged the effects were in no way exceptional.

The main results from both centres are set out in the following table:

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Milford, 1949

Effect of Irrigation, dissolved nitrate, and fertilizer nitrogen

	Mean Yield	Irrigation, inches 0	6½	8½	13	S.E.	Increase for Nitrate	S.E.
Roots, tons ..	16·3	14·3[1]	17·5	17·8	16·9	0·42	0·1	0·59
Sugar % ..	12·2	12·0[2]	12·3	12·5	12·3	0·13	—0·2	0·19
Sugar, cwt. ..	39·9	34·6[3]	42·9	44·5	41·6	1·34	—0·6	1·89
Tops, tons ..	19·0	14·4[4]	20·5	20·3	21·0	0·44	2·1	0·62
Plants, thous...	37·5	37·8[5]	38·1	37·5	36·4	0·33	0·7	0·47
Noxious N ..	68·5	81·5[6]	63·3	59·6	59·2	3·30	7·0	4·60

[1] 0·30 [2] 0·09 [3] 0·94 [4] 0·31 [5] 0·23 [6] 2·3

	Fertilizer Nitrogen, cwt. per acre 0·4	0·7	1·0	1·3	S.E.
Roots, tons	16·8	16·3	16·6	15·6	0·22
Sugar %	12·4	12·3	12·1	12·0	0·064
Sugar, cwt	41·6	40·2	40·2	37·5	0·60
Tops, tons	18·0	18·7	19·2	20·0	0·27
Plants, thous.	37·9	37·7	37·4	36·8	0·23
Noxious N	63·1	64·4	72·8	73·9	1·72

Kesgrave, 1949

Effect of irrigation and Fertilizer Nitrogen

	Mean Yield	Irrigation, inches 0	4	5½	S.E.	Nitr'n., cwt. per acre 0·4	0·85	1·3	S.E.
Roots, tons	14·4	11·3	15·3	16·4	0·35	14·6	14·3	14·1	0·23
Sugar %	14·5	13·6	15·0	15·0	0·18	15·1	14·6	13·9	0·082
Sugar, cwt.	42·0	30·8	46·0	49·3	1·25	44·5	42·1	39·5	0·72
Tops, tons	10·2	9·5	9·7	11·3	0·29	9·3	10·4	10·8	0·25
Plants, thous.	26·6	26·9	26·5	26·4	0·34	27·7	27·3	24·8	0·33
Noxious N	69·6	78·3	65·9	64·5	3·6	59·6	70·9	78·2	1·8
Dirt Tare %	16·0	21·2	14·7	12·3		15·6	16·8	15·7	

The features of the Milford experiment were the very early and severe virus yellows attack and the exceptionally low sugar content of 12·0 per cent. The result was only a moderate yield of 34·6 cwt. of sugar on the dry plots in spite of a very high plant population. The lightest watering, 6½ inches in five applications, increased the output of sugar by 8·3 cwt. per acre, but there was no definite increase for the higher levels of watering. The heaviest watering, 13 inches in nine applications, gave a smaller yield of sugar per acre than 6½ or 8 inches, but not significantly so. Nitrogen in moderate dressings was ineffective and at the highest rate it significantly depressed the yield of sugar. There was no marked interaction between the effect of water and nitrogen. So far as the other attributes of the crop were concerned the sugar percentage was slightly but significantly raised by watering and depressed by nitrogen. Tops were increased by 6·1 tons by the lightest watering, with no further response for heavier applications, they were also slightly increased by nitrogen. Plant population was slightly reduced by the heaviest watering and by the highest nitrogen application. The figure for noxious nitrogen was greatly reduced

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by watering, and markedly increased by nitrogen. The effect of adding Chilean potash nitrate, providing 0·4 cwt. N and 0·3 cwt. K_2O per acre, in the irrigation water was negligible so far as sugar was concerned, but it increased the tops by 2 tons and like fertiliser nitrogen it tended to raise the proportion of noxious nitrogen.

At Kesgrave with a crop of 30·8 cwt. of sugar on the dry plots, 4 inches of irrigation gave no less than 15·2 cwt. sugar per acre and there was a further increase for 5½ inches. Nitrogen reduced the quantity of sugar per acre significantly. These two factors showed a marked interaction, for the benefit from watering was much less when nitrogen was present, or alternatively the poor effect of nitrogen was most conspicuous on the watered plots.

Effect of 5½ inches water, no nitrogen	23·4	cwt. sugar
Effect of 5½ inches water, with nitrogen ..	12·9	,, ,,
Effect of 1·3 cwt. nitrogen, no water	1·2	,, ,,
Effect of 1·3 cwt. nitrogen, with 5½ inches water	—9·3	,, ,,

At Kesgrave the effects on the other attributes of the crop were closely parallel to those observed at Milford. Watering increased the sugar percentage significantly, and nitrogen depressed it by 1·2 per cent. Both water and nitrogen increased the tops. Heavy nitrogen depressed the plant number. There was a decrease in noxious nitrogen due to watering, and an increase due to nitrogen. The roots on the dry plots were noticeably more hairy than the rest and picked up more soil at lifting time. The difference was clearly reflected in the figures for tare.

The main conclusions from the experiments of 1949 is that in a very dry year with an exceptionally hot dry summer, 6 inches of irrigation water was sufficient for a full crop, though it is possible that a disease-free crop might have used more. The interaction of nitrogen and watering will be further examined in future experiments.

Two Course Rotation

When agricultural salt was included from 1940 onwards as a treatment in the standard manurial experiments on sugar beet carried out in all Factory areas it soon became clear that 5 cwt. of salt per acre produced substantial increases in the yield of sugar over a wide range of conditions. The question then arose whether repeated applications of salt on the same land would continue to be effective for sugar beet. There was the further possibility, widely believed by farmers, that continued use of agricultural salt might damage the soil either structurally or in other ways. To test these points a long-period experiment was begun at Rothamsted in 1942. In order to break the sequence of sugar beet crops, a two-course rotation of sugar beet followed by barley was adopted, barley being chosen because it was the one cereal popularly supposed to benefit from salt dressings.

Two blocks of land were assigned to sugar beet and barley in Long Hoos field, the crops being changed over each year to give the two-course rotation. The following scheme of treatments was adopted. Four rates of salt application, 0, 2½, 5, and 7½ cwt. per acre, were used for the sugar beet. The salt was applied either before the winter ploughing or harrowed into the seedbed in spring

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a few weeks before drilling the seed. On one set of plots these treatments were given to the sugar beet only, the following barley crop receiving no salt; on the remaining plots the barley also received salt treatments but at only half the rate given to sugar beet on the same plot. The sugar beet also tested muriate of potash at approximately 0, 2, 4 cwt. per acre, the muriate dressings being the equivalent of $1\frac{1}{4}$ and $2\frac{1}{2}$ cwt. of agricultural salt. All dressings were repeated according to the above scheme on their respective plots, hence at the heaviest rate certain plots received $7\frac{1}{2}$ cwt. of salt per acre to sugar beet followed next year by $3\frac{3}{4}$ cwt. per acre to barley. For the first two sugar beet crops in 1942 and 1943 and the first barley crop in 1943 the early application of salt was broadcast in the spring on land that had already been ploughed in the previous autumn. Subsequently for the six years 1944-49 inclusive, the early application of salt was always ploughed-in in winter for both crops.

The average results of the direct application of salt and muriate of potash to sugar beet taken over the 8-year period 1942-49 are given in Table I. The figures are the means of the two methods of applying salt on plots, half with salt to sugar beet only and half with salt repeated at half rate to barley.

Table I. Sugar Beet 1942-1949

Effect of Agricultural Salt and Muriate of Potash

Sugar: cwt. per acre

Salt to sugar beet cwt.	Muriate of potash 0	2 cwt.	4 cwt.	Mean
0	40·9	43·7	45·9	43·5
$2\frac{1}{2}$	50·0	47·8	49·0	48·9
5	50·0	50·2	49·5	49·9
$7\frac{1}{2}$	48·0	49·4	50·0	49·1
Mean	47·2	47·8	48·6	47·9

The level of cropping was very good. Agricultural salt in the absence of potash gave on the average the extraordinary increase of 9·1 cwt. sugar per acre for the $2\frac{1}{2}$ cwt. dressing. There was no indication of any benefit from heavier dressings of salt. In fact there was some suggestion that in the absence of potash $7\frac{1}{2}$ cwt. salt per acre was too much. Potash without salt also gave notable increases in the yield of sugar, but on a much smaller scale than the equivalent amount of salt. When salt was supplied there was no further increase due to potash, but salt still increased the crop substantially even when large amounts of potash were supplied. These results are in accord with those of the Factory Series of sugar beet fertiliser experiments in which on an average of 140 trials 5 cwt. of salt in the absence of potash gave 5·1 cwt. sugar, 2 cwt. of muriate of potash in the absence of salt gave 2·8 cwt. of sugar, and the two nutrients in combination gave 5·5 cwt. sugar.

The yearly increases due to salt in the absence of potash and to potash in the absence of salt are given in Table II for the eight crops of sugar beet grown in 1942-49.

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Table II

Effect of salt (without potash) and of muriate of potash (without salt) in individual years 1942-49
1Na, 2Na, 3Na = 2½, 5, 7½ cwt. salt per acre to sugar beet, repeated at half rate to barley on half the plots
1K, 2K = 2, 4 cwt. muriate of potash per acre to sugar beet only
Sugar: cwt. per acre

	1942	1943	1944	1945	1946	1947	1948	1949	Mean
No Salt, No Potash	54·5	57·0	27·2	58·3	52·3	23·7	33·4	21·0	40·9
Increase for:—									
1Na	6·6	9·3	9·4	8·0	7·9	13·5	10·3	7·4	9·1
2Na	9·0	9·5	8·9	6·2	5·6	15·8	8·4	8·9	9·0
3Na	6·7	5·7	5·0	4·4	3·7	14·2	8·5	8·7	7·1
1K	−0·9	5·7	−0·1	4·5	−0·8	7·6	0·8	5·7	2·8
2K	2·8	6·3	4·4	3·2	6·9	7·4	2·3	6·6	5·0
SE+	2·63	3·07	2·47	2·15	2·71	3·54	3·12	1·36	—

The yearly responses to the first two rates of application of salt were large and very consistent. In every year except 1948 the highest dose of 7½ cwt. salt gave less sugar than the 5 cwt. application, and in 6 years 7½ cwt. salt gave less sugar than 2½ cwt. of salt, but none of these differences between rates of application of salt was significant in a single year. The comparatively poor effect of the heaviest dressing was most noticeable in the earlier years of the experiment; by 1947 the heavily treated plots were practically as good as the others. The data give no support to the idea that agricultural salt may lose its effectiveness for sugar beet if repeated at frequent intervals on the same land.

The effect of muriate of potash varied widely from year to year. In half the seasons the lower rate was ineffective, but in the others it gave an increase of about 6 cwt. of sugar per acre. The double rate gave better results even in the years when the single dose failed. As with salt there was no indication that the effect of potash fell off after many repetitions on the same plots. Indeed both nutrients at all rates gave bigger increases in the last four crops than the first four.

For the years 1944-49 there were no appreciable differences between salt ploughed-in in winter and salt broadcast on the seedbed in spring, and no effect from applying additional salt to the preceding crop of barley. Averaging all levels of salt, the figures were:

Sugar: cwt. per acre

No Salt	38·7
Increase for:—	
Salt ploughed-in in winter	6·1
Salt broadcast on seedbed in spring	6·3
Salt applied to sugar beet only	6·1
Salt to sugar beet and at half rate to barley	6·3

Measurements of the effects of salt and potash were made on the other attributes of the crop and a condensed summary is given in Table III.

Table III

Effect of salt (mean of all rates of application) without potash, and potash (mean of all rates) without salt

	Roots tons	Tops tons	Sugar per cent.	Plant No. thous.
Mean yield, no salt, no potash	11·7	10·7	17·3	23·8
Increase for:—				
Salt, no potash	2·1	1·1	0·5	1·0
Potash, no salt	0·9	0·6	0·4	0·5

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Salt had a markedly beneficial effect on all attributes, including plant number. Potash was about equal to salt in raising the sugar content, but only about half as effective on the remaining attributes. Examination of the yearly results shows that there was no reduction of plant number even in the presence of the highest dressings of salt and potash used together.

Effects on Barley. On the barley crop potash is always residual. Half the barley plots testing salt have salt applied directly at half rates and the remaining half tested only the residues from salt treatments given to the preceding sugar beet crop. The effects of these treatments averaging methods of applying salt are set out in Table IV.

Table IV. Barley: cwt. per acre, 1943-49
Effect of residual potash, and salt (direct and residual)

Salt cwt.	Muriate of potash cwt. 0	2	4	Mean
0	27·7	28·3	27·6	27·9
1¼	28·5	29·0	28·7	28·7
2½	27·6	27·9	27·3	27·6
3¾	27·1	29·0	28·4	28·2
Mean	27·7	28·6	28·0	28·1

Very satisfactory crops of barley were grown each year. On the average of the seven years neither residual potash nor salt had much effect on the yield of barley. The lightest dressing of each gave an average increase of only about 0·8 cwt. grain and there was no further increase for higher rates. In certain years, however, the effects were appreciable. In 1947 and 1949 the effects of residual potash were significant. In 1943 and 1945 there were significant improvements from salt, the direct effects of salt at half rate being greater than the residual effects of the full dressings. The mean effect on barley straw of residual potash and of salt directly applied was negligible.

Salt application produced visible effects on the physical state of the surface soil on this heavy loam when the land was in plough furrow. This was specially noticeable on the sugar beet areas on plots receiving the heavier applications in repeated dressings although it could also be observed on the barley land. The furrows on plots with much salt had a smooth slightly glazed appearance and were lighter in colour than those without salt. The effect was most noticeable after heavy rain. After harrowing the tilth on the heavily salted plots was noticeably more lumpy than the rest, but rolling produced a satisfactory seedbed everywhere and, as the figures show, the sugar beet plant population was not adversely affected. When lifting took place in wet weather the soil was more sticky on the heavily salted plots.

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THE FARMS

By J. R. Moffatt

Rothamsted

During the year under review, no major changes of policy have taken place. Now that farming conditions are reasonably stable, the aim has been to secure sufficient staff, equipment, and materials to maintain a high standard of productivity both on the experimental field plots and on the non-experimental areas of the farm.

Field Experiments

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

The number of experimental field plots, planned by the Field Plots Committee, increased from 1,412 in 1948 to 1,536 in 1949. The weather was helpful throughout the year in enabling the work on these plots to be kept up to schedule, but it had a detrimental effect on the yield of all root crops and grass plots. In the new and complex ley-arable experiment which started in the autumn of 1948 (and was described in the 1948 report) many difficulties were encountered, some of which had been anticipated. It was fortunate that only a third of the experiment was started during the year, and that the growth of grass on the plots to be grazed was severely limited by the drought. Modifications have been made in the experiment which should overcome most of the difficulties in the future. The direct re-seeded grass plots on the old grass field took well and a very satisfactory plant remains for the 1950 season. Similar plots on the old arable land had to compete with strongly-growing arable-land weeds, and were also much more affected by the drought, and the plant suffered in consequence. Spraying was done with 15 per cent. B.O.V. (sulphuric acid) to kill the Knot-grass (*Polygonum aviculare*), in which it succeeded, but some plots have had to be ploughed up ready for a fresh start in 1950, while others will need patching.

Cropping

The area farmed remained at 474¾ acres, of which 242 acres were under tillage crops and 102 under leys, giving a total arable area of 345 acres. The main crops were: wheat 72 acres, barley 69 acres, oats and dredge corn 17 acres, potatoes 31 acres, mangolds, sugar-beet and kale 25 acres, with smaller areas of linseed, rye, beans, peas, lucerne and vegetables. 5 acres, all under experiment, were fallowed. The main difference between the 1948 and 1949 cropping was the decrease in the area under wheat and a corresponding increase in that of barley, and an increase in the area under temporary ley. The area of permanent grass was reduced to 99 acres by the ploughing up of part of the area previously devoted to a grazing experiment, and it is hoped to reduce the permanent grass still further in 1950.

Spring Work

The winter corn was drilled by the middle of November, 1948, most of it under reasonable conditions, and the very mild weather enabled it to germinate rapidly.

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The early months of 1949 continued generally mild and dry, and the excellent condition of the land made it possible to replough all the ground for roots, except the classical mangold field. The conditions also greatly favoured the early preparation of seedbeds for spring corn, which was all sown under excellent conditions. The continuation of the dry weather throughout March (with the exception of a light snow-fall early in the month), April, and early May enabled the seedbeds for the root crops to be thoroughly prepared, and all spring sowings were completed early in May. By the middle of the month, the dry weather and low night temperatures were retarding the growth of most crops, but the latter half of May brought much-needed rain which caused an almost immediate improvement in the appearance of all crops.

Summer Drought

The dry spell set in again in early June, when only 0·64 ins. of rain fell, and a long summer drought then developed. During the four months June-September inclusive, only 4·03 in. of rain fell, compared with the average of 9·68 in. The mean temperatures and hours of sunshine were well above average for each of these months.

The hot and dry conditions did not appear to affect the cereal crops, which looked very promising throughout the season, except on one field where the wheat plant was thin. Some of the wheat showed signs of coming into ear in mid-June, and all crops ripened earlier than usual. Several of the corn crops were treated with herbicides with very satisfactory results. One field of barley after a well-manured crop of potatoes became lodged fairly early, while thunderstorms about mid-July, although affording some relief from the drought, caused further lodging, although the damage was only severe in patches.

The hand-pulling of wild oats on Broadbalk wheat plots, carried out each year mainly by volunteer workers from the Laboratory staff, is effectively reducing the infestation of this weed. In 1949, section 5, which was fallowed in 1948, contained very few wild oats, but the area was hand-pulled thoroughly. Sections 1 and 2, after a year's fallow 3 and 2 years ago respectively, contained quite a few oats, but each was hand-pulled on two separate occasions, and if labour can be secured for this operation each year until they are next fallowed, the reduction in the wild oat population will be of prolonged benefit. Section 3, due to be fallowed in 1950, contained the heaviest infestation, but the plots in this section were cleared as far as possible, with the exception of plot 8, where there were too many weeds to be pulled by hand. The 1950 fallowing will considerably reduce the weed population of this section, after which the aim will be to prevent another building-up of weeds, by hand-pulling the area each year.

The linseed crop made good initial growth after fairly early sowing, but the drought then affected it badly and subsequent growth was very slow. There was also a very bad infestation of Fat Hen (*Chenopodium album*) in the crop, but this was very effectively controlled by spraying and dusting with MCPA herbicide. The

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crop suffered slight initial distortion but soon recovered. The estimated yield of 5 cwt. per acre of seed is less than half the normal yield.

The experimental crops of peas and beans looked well throughout the season, except that the beans were severely attacked by bean aphis which, despite several sprayings with nicotine, considerably reduced the yield. A non-experimental area of beans which escaped early damage by birds was later so severely attacked that it had to be cross-drilled with a mixture of spring cereals. It was fortunate that this was done, as the beans which survived the bird damage were later so badly attacked by bean aphis that the harvested crop consisted almost entirely of cereals.

The dry weather retarded the growth of weeds in the root crops, but also the growth of the crops themselves. This enabled the regular farm staff to undertake the singling of the sugar-beet and mangold crops, which was completed towards the end of June. Fortunately the flea beetle was not so active as usual, and no precautionary dustings were needed on these crops. The kale crop, which was sown early, escaped with negligible damage, but a few later-sown areas were badly damaged. The root crops looked backward throughout the summer, very little growth being made, while the sugar-beet crop also had to contend with an early and severe attack of Virus Yellows disease.

Harvest Operations

The early ripening of the corn crops led to harvesting starting earlier than usual. Weather conditions were excellent throughout. Much of the corn which was cut by binders was carted direct from the binder rows without shocking, and was either stacked or threshed in the field. The grain from the areas cut by combine harvester was beautifully dry and free from weed seeds and green material. The wheat was sold without further cleaning, but because of the glutted state of the market the barley was held in store in the hope of better prices later. All harvesting operations were finished before the end of August and the threshing of outside corn stacks followed immediately. Yields of wheat and barley were both very good, and good yields are also anticipated from the oat crop.

Potatoes

The planting of the fairly large area of potatoes without additional labour was made possible by the use of a 2-row potato dropping attachment fitted to the hydraulically controlled toolbar of a tractor. This work was carried out in conjunction with the National Institute of Agricultural Engineering, and proved very speedy and efficient, for, as was shown by the experimental plots, the machine planting was superior to hand-planting. Besides the speed of planting, the dropper has the advantage over hand-planting that the tubers are planted direct into moist soil, whereas with hand-planting the tubers are often planted in ridges which have partially dried out. This factor is also likely to affect considerably the loss of plant if Dry Rot is present in the seed tubers. In a wetter year, it is possible that the difference in favour of the dropper would not be so marked, but the advantage is likely to remain with the dropper nevertheless. It has been the practice for several years to put

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dung for the potatoes in the ridges just before planting, but manure added in this way would foul the openers of the machine. None was therefore used in 1949 on the areas planted by this machine. In future, dung will be ploughed-in during the winter months for the potato crop.

About half the potato area was planted with seed of Scottish "A" stock, the remainder being planted with the same variety but with seed grown at Rothamsted in 1948 for which an English "H" certificate was obtained.

The crop made reasonable growth during the first part of the season, but in July, August and September growth was very slow and ripening took place much earlier than usual. There was no sign of Late Blight during the season, so no precautionary sprayings were done. The haulm was burnt off with sulphuric acid before lifting began, to facilitate this operation. The lifting of the experimental areas started in mid-September, and was finished before the end of the month. This was followed by the lifting of the non-experimental crop, for which schoolchildren were employed. Yields were only about half the 1948 crop, and individual tubers were smaller than usual, with many damaged by cutworms. The crop has been stored under cover in the Dutch Barns to an average depth of 10 feet.

Grassland and Livestock

Haymaking started early in June, but the drought considerably reduced yields. The light crop was made under excellent conditions, however, and was stacked under the Dutch barns at the farmstead. In future most of the hay will be gathered by a pick-up baler, as not only will it be easier to handle and transport, but needing a smaller team of workers it will enable the singling of the root crops to be carried out without the interruption of haymaking.

The grass and clover seeds undersown in the cereal crops in 1949 took quite well and generally look quite promising for next season. On one area where the nurse crop of barley was badly lodged, however, a considerable amount of patching will have to be done. One area which was sown without a cover crop became badly infested with Fat Hen (*Chenopodium album*) and creeping thistle, but spraying with MCPA herbicide effectively controlled both these weeds and although the plant of grasses and clovers is rather thin, it will be left down.

The effect of the drought on the pasture land was very severe. The spring flush lasted only a very short time and by mid-July the fields were very parched. A second top-dressing of sulphate of ammonia was given to some fields, but as there was no rain to wash it in it had the unusual effect of burning up some of the clovers. Supplementary food had to be given to some of the stock from July onwards, and throughout July, August and September the grass fields presented much the same appearance as the stubble fields. Hay and straw had to be carted to the stock in September, and many of the cattle had to be sold before reaching the desired degree of finish. Many of the most forward of the cattle were brought into covered yards in October, to fatten them off as soon as possible, but several which should have fattened off the grass are now being over-wintered. 66 cattle were purchased during the winter of

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1948/49, the majority of which were Irish steers. Some were out-wintered, but most were brought into covered yards to tread straw into farmyard manure. During the year ending 30th September, 1949, 71 fat cattle were sold to the Ministry of Food.

The number of Scottish Half-bred sheep in what originated as a Half-bred flock was further reduced during the season by culling, the replacements being home-bred ewe lambs out of the old ewes by Down rams. 140 ewes and some ewe lambs were put to Oxford and Suffolk rams to lamb early in April, but very few of the ewe lambs bore lambs and the lambing percentage was low. The flock has done reasonably well under difficult circumstances. The drought and consequent shortage of grass reduced the milk supply of the ewes, which affected the rate of growth of the lambs, very few of which were sold fat before the end of the year. They were folded on kale from early November, and have since improved considerably; and most will be sold early in 1950. 68 of the best ewe lambs and a few wether lambs have been retained for grazing experimental plots at Rothamsted and Woburn, and some of the ewe lambs may be brought into the ewe flock at the end of the grazing season.

Autumn Work

The very protracted drought lasted until the end of the first week in October, after which heavy rain was experienced for the rest of the month. October, normally the wettest month of the year with 3 in. of rainfall, was doubly so this year, producing over 6 in. of rain in the last three weeks, of which 2·67 fell on two days. More rain fell in this month than fell in the previous 5 months, and the land, much of which had been too hard for ploughing and too dry to work down to seedbeds, became far too wet to work. The preparation of the land for winter corn was thus considerably delayed, only a few experimental areas being sown by the end of October, 1949. However, a drying spell early in November enabled the drilling to be completed by the middle of the month, although on several occasions the conditions were not as favourable as could have been wished. The acreage of winter corn for the 1950 harvest has been considerably increased.

The delay in the start of drilling also delayed the harvesting of the sugar beet and mangolds. Mangold yields were well below average, while the sugar-beet crop was the most disappointing crop of the year. This was because of the combined effects of the drought and an almost hundred per cent. infection with Sugar Beet Yellows virus disease. Individual roots were small and the yield was considerably below normal. The sugar content too was disappointingly low, the average as returned by the factory being 14·7 per cent.

The weather in December, 1949 was much warmer and drier than usual, and this enabled the winter ploughing to be continued almost without interruption. Several fields have already been ploughed a second time, and an area of about 15 acres which has been under a long-term ley was ploughed before the end of the year.

Labour

The labour position this year was more satisfactory than for many years past. This was due primarily to the increase in the permanent staff made possible by the erection of the new cottages

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for farm workers, but the weather played its part in that the growth of weeds was retarded and those that grew were easily destroyed in one operation. The amount of seasonal labour required during the year was therefore reduced to a minimum. The only occasions such labour was needed were for potato lifting and for sorting the last of the large 1948 crop of potatoes. The last sales were made by the Ministry of Food during late May and early June, by which time the regular staff were engaged in root singling. Fortunately the potatoes stored extremely well in the large heaps, and there was very little wastage even as late as June, 1949.

Machinery

Several additions to the list of implements were made during the year. A new tractor complete with many of its own range of specialized implements was purchased, and it is hoped that this will in future undertake many of the jobs on small plots previously undertaken by horses. A small single-wheeled motor hoe has been bought to facilitate the hoeing of small experimental areas where headlands are reduced to a minimum, and a new rotary hoe will keep clean the paths between the plots.

Buildings

Towards the end of 1949, a start was made with the erection of a new farm workshop and implement shed, to house the gradually increasing number of farm implements, many of which are at present housed in buildings designed and needed for other purposes. The building will be completed early in 1950.

Local Show Successes

Two horsemen and two tractor drivers took part in the local ploughing match, and between them won 2 first prizes, 3 second prizes, and a 3rd prize.

Conclusions

The execution of the year's work has been generally less difficult than usual. There was sufficient permanent staff to deal with most operations, which were therefore done on time, while dry weather extra equipment, and the use of herbicides enabled weeds to be kept under control. The weather also greatly facilitated the harvesting of the cereal crops, and enabled work to be kept up to schedule throughout the season. The results of the year's work, due to circumstances beyond our control, have been somewhat disappointing, for although the yields of cereals were satisfactory, those of all root crops, beans and linseed were low.

Woburn

The re-organization of the Woburn Farm, which commenced in 1947, when the management was merged with that of the Rothamsted Farm, was continued with satisfactory results. The main objectives of the year's work were to arrange the cropping so as to clean up, without resorting to bare fallowing, those fields not tackled in the previous two years, and to mechanize field operations where possible to enable the existing staff to tackle the increased arable acreage, and the anticipated higher crop yields, with the minimum expenditure on seasonal labour or outside contractors.

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Cropping

The cleaning of several fields was tackled by intensive cultivation in preparation for, and during the growth of, a much increased area of potatoes, with a smaller area under sugar beet. The total area farmed was 127 acres, of which 52 acres were under cereal crops, 13 acres under various experimental crops or fallow, and the remaining 38 acres of arable land under potatoes or sugar beet; 24 acres were under grass. The area under experimental field crops was increased by the cropping, after a 2-year fallow, of the Permanent Wheat plots in Stackyard Field, although the actual number of plots was reduced to 422.

Mechanization

The partial mechanization of many of the operations proved very successful in that the work was completed within a short period and less seasonal labour was required. The most important of these operations was potato planting, which was carried out by 3 workers using a simple 2-row potato dropping attachment fitted to the toolbar of a tractor using a hydraulic lift. A second tractor was purchased during the year with a range of its own specialized equipment, and this not only undertook many of the operations previously performed by horses, but enabled both the experimental and non-experimental work to be kept up to schedule. Other smaller self-propelled machines have greatly facilitated the working of the experimental plots, while the replacing of out-of-date equipment by modern machinery has aided the execution of land work throughout the year.

The amount of seasonal labour required during the year showed a satisfactory decrease of approximately 30 per cent. over 1948, and it is hoped that in the years immediately ahead, seasonal labour will only be required for root singling, potato picking and threshing, and that for the latter will be provided from the Rothamsted staff during the winter months. Eventually it is hoped to mechanize both these operations.

Buildings

It was not possible to erect the new implement sheds, tractor garages, and covered barns which it was hoped would be erected during the year, but it is confidently expected that these buildings will be erected in 1950. The electrical circuits have been considerably extended, however, to provide adequate lighting and power points about the buildings, and it is hoped that the extended use of electricity now possible will reduce the amount of labour required around the farmstead.

Crops and Cultivations

The autumn corn was drilled during the first half of November, 1948, and although the soil conditions were far from ideal, about 30 acres of wheat and rye were sown. The winter remained favourable to farm work, the rainfall during the first three months of 1949 being well below normal, while there were few frosts, none of them very severe or prolonged. The mild weather encouraged the early germination of weed seedlings, which were destroyed by ploughing in, and on many areas three ploughings were given. Spring sowing operations began about mid-March and all crops were sown in good

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time under favourable conditions. Early growth of all crops was slow, however, because of the dry weather and low night temperatures which occurred in the first half of May.

Fleabeetle damage, so prevalent in 1948, was almost negligible this year, except for an early attack on a small area of rape, which had to be resown, but periodic dusting with D.D.T. on susceptible crops was carried out as a precautionary measure.

The dry spring developed into a severe summer drought. In the four months June to September, 1949, the rainfall totalled only just over 4 in. compared with the average of 8·8 in., while the hours of sunshine and mean temperatures were well above normal. The effect of the drought was most severe on those experiments where the ground had to be prepared for the transplanting of cabbages and leeks. The cultivations were considerably delayed by the dry state of the soil, the plants had to be watered in on several occasions, and much patching was required to ensure a full plant. A severe aphis attack in late summer caused a further set-back to the cabbages.

The grass and clover seeds sown under the corn crops withstood the drought far better than in 1947, and all survived with a satisfactory plant. The grasses and clovers undersown in 1948 as experimental green manure crops made such rapid growth in the spring of 1949 that by the time the spring-sown rape and lupins were ready to be ploughed in the former crops were so heavy that they had to be cut and weighed off.

The dry spring and summer retarded the growth of pasture grass, and the spring flush did not last long. Subsequent growth was very slow, and the pastures were very bare for about 3 months, despite top-dressings of nitrogen. The fattening cattle were ready for sale during July and August, leaving only store beasts on the bare pastures. Hay yields were quite satisfactory for the dry season, and the crop was carted in good condition.

The weed problem was far less serious than in the past few years. The mild winter encouraged the early germination of many weeds, which were then destroyed, while the crops were sown under satisfactory conditions and were able to compete strongly with the later-germinating weeds. The dry weather prevented the weeds from growing very fast, and so enabled the motor and horse hoes to keep them under control. Herbicides were also used on cereal and pea crops. The fields have therefore presented a cleaner and tidier appearance than for several years past.

Corn looked very promising throughout the season, although some of the barley became lodged fairly early and other patches lodged after thunderstorms early in July. Wheat and oats stood well despite fairly heavy top-dressings of nitrogenous fertilizers. Harvesting operations started rather earlier than usual, and were continued almost without a hitch until they were finished almost exactly a month later. Much of the corn was not shocked, but was carted straight from the binder rows. The threshing of outside stacks of wheat and rye was done soon after harvest, and although the yields were rather lower than their appearance when growing suggested, the quality was excellent, and much of the rye was sold for seed. The barley, which was threshed later, was rather disappointing in both yield and quality.

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The potatoes made reasonable growth in the early part of the season but growth was slow during August and September and the crop began to die off much earlier than usual. Because of the dry weather there was no incidence of Late Blight, and no spraying against this disease was therefore required. The harvesting of the experimental plots was completed in September, and yields were far higher than was anticipated, although the tubers were rather smaller than usual, with many affected by scab. The lifting of the large non-experimental area was completed in October, the haulm having been burnt off with acid to facilitate lifting operations. The yields here were much lower than average, and the tubers smaller, and there was also some damage by cutworms. The crop has been stored in an enclosed building at the farmstead to a depth of 10 ft. and will be sorted during the winter. The lifting operations were interrupted by the sudden break in the weather which took place at the end of the first week in October. During that month the rainfall was over 5 inches, almost twice the average.

Sugar beet proved the most disappointing crop of the season, despite the abundance of sunshine. The crop was affected very early with Sugar Beet Yellows virus, which spread throughout the whole crop. This disease, and the severe drought, resulted in low yields and a very disappointing sugar content. Harvesting was completed by the regular farm staff by the middle of December.

The rainfall during November, 1949, was slightly higher than average, but December only had half the average, and ploughing was carried out without much interference. 33 acres were sown with wheat and rye for the 1950 harvest, and early damage by game to these crops has been less than for several years past.

Livestock

Cattle

A small bunch of young cattle were over-wintered outside, mainly on sugar beet tops and oat or barley straw, and the mild weather enabled them to maintain their condition. A smaller number of stronger cattle were yarded during the winter to make F.Y.M. for experimental plots and were later sold fat off the grass.

Pigs

The small Large White pig herd has been maintained, most of the progeny being retained and carried on to bacon weight.

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WOBURN EXPERIMENTAL STATION

By H. H. Mann

Season

The season of 1949 was as great a contrast with that of 1948, as it is almost possible to conceive, and the very dry summer months, especially June, July and September, made many of the usual operations in those months exceedingly difficult and sometimes impossible. All experiments which involved transplanting of crops during those months were affected, and in some cases, notably in the cabbages following green manuring crops, the results were consequently very different from what we have been accustomed to get in this experiment. The amount of grazing during the summer in the ley experiment was far less than usual, but, on the other hand, corn crops were at least up to the average and in the experiments where sugar beet or potatoes were grown, the reduction in yield, even on a light land farm like Woburn, was far less than might have been expected. The meteorological records from October 1948 to the end of 1949 are shown below.

Meteorological Records for 1948-1949

Month	Rainfall		Bright Sunshine	Temperature			
	Total fall	No. of rainy days		Maximum	Minimum	1 ft. in ground	Grass minimum
1948	in.		hours	F	F	F	F
October	2·27	12	98·2	56·3	42·3	51·1	37·7
November	1·21	15	74·7	49·8	37·7	44·7	34·1
December	2·25	18	58·4	47·1	36·3	41·9	32·3
1949							
January	0·96	12	69·0	46·5	35·3	40·2	30·2
February	1·13	10	116·5	48·9	33·8	39·5	27·0
March	1·35	8	103·4	46·8	33·1	40·6	28·1
April	1·65	11	184·2	58·7	41·0	49·9	36·0
May	2·14	12	213·5	60·5	41·4	53·8	36·3
June	0·74	6	230·1	69·1	48·1	63·2	42·0
July	0·93	6	236·6	74·9	51·7	68·3	44·5
August	1·69	9	222·6	73·6	51·6	64·6	45·1
September	0·81	6	153·7	71·2	53·3	62·8	47·4
October	5·02	15	129·2	60·3	45·4	53·5	40·2
November	2·66	18	74·9	48·7	36·9	42·4	32·6
December	1·20	16	57·8	47·1	37·2	40·9	32·4
Total or Mean for 1949	20·28	129	1791·5	58·9	42·4	52·1	36·8

Field Experiments

The field experiments at Woburn are now conducted under the direction of the Field Plots Committee at Rothamsted, and that Committee will report separately on them. There are, however, a few points in connection with them that may be mentioned here.

In connection with the very serious infestation of wild oats on the permanent barley plots in Stackyard Field, records were maintained as to the number of plants which grew on this area, which, fortunately, was again kept fallow in 1949. On the worst portion of this area, the number of growing wild oat plants was counted on sample plots before most of the cultivations during the year. As noted last year, after a year of fallowing and intensive cultivation in February 1948, there were nearly 4½ million wild oat plants per acre and 3½ million a couple of months later. It is in the spring that most of the dormant wild oat plants germinate with

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a subsidiary period of germination in the autumn. The gradual disappearance of the pest and the length of time it takes to get rid of it once the ground is badly infested is shown in the following series of figures.

	Number of wild oat plants per acre
May 1948	2,400,000
September 1948	1,200
November 1948	584
March 1949	32,625
May 1949	14,888
October 1949	4,400
January 1950	3,108

It is evident that one year's fallow leaves still enormous numbers of viable wild oat seeds in the soil: two year's fallow gets rid of most of these, but even after three years there are still quite a fair number of seeds still capable of growing. Two other interesting points emerge from our observations. First, practically all the wild oat plants spring from seeds in the top few inches of the soil: it is rare to find a living oat plant rising from below the plough level. Second, the greater number of autumn plants in 1949 over 1948 seems probably to be connected with the dry summer in 1949 which would lead to the greater likelihood of water penetrating the hard skin of the wild oat seed. On the whole, it is clear that even three years of intensive fallowing will not entirely eradicate wild oats when once they have really become a heavy infestation.

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. For most of the crops which we have studied, 1949 has been a very good season, giving some of those more suited to warmer climates a greater chance of ripening than was the case, for example in 1948. The crops of this kind grown in 1949 have been hybrid maize from the United States, soya beans bred for long days in Sweden, serradella, and birdsfoot trefoil for forage.

With regard to maize, where we grew several of the early Wisconsin hybrids (seed of which was kindly supplied by Dr. Neal of that State), we were able to ripen all the types supplied and to get a crop much earlier than was the case in 1948. The yield was also much higher, and the ripening about 30 days earlier than in 1948. The yields obtained are shown below:—

Variety	*Note as to earliness*	*Yield of dry grain per acre*
Wisconsin 275	Very early: rather dwarf plants ..	2·20 tons
Wisconsin 240	Fairly early: taller than 275 ..	1·69 tons
Wisconsin 1600	Earliness as 240	1·03 tons
Wisconsin 255	Latest of the four varieties and the tallest	1·20 tons

The only manuring given was 3½ cwt. of sulphate of ammonia per acre on May 17th, the maize having been sown on April 21st. To get these yields it is necessary to obtain seed direct from the breeders: to test this point we grew Wisconsin 240 from our own seed of this

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variety grown in 1948; this only gave a yield of 1·20 tons per acre as against 1·69 tons for the freshly imported seed. It seems that these early hybrid varieties of maize could have an important place in British agriculture, especially among small holders, very little seed being needed and the crop being used for feeding without threshing, after grinding the whole of the cob together.

With regard to soya beans, we have grown a number of varieties developed by Holmbergs of Sweden, as suited for higher latitudes than the soya bean areas of the U.S.A. and so ripening under our conditions when the usual American types will not do so. The usual difficulties with this crop in the past have been that the high yielding varieties would not ripen, and the types which could be relied on to give ripe beans were very poor yielding. The Swedish soya beans that we have grown in 1949 are dwarf types and can be grown much closer spaced than is usually the case, but even with our usual spacing we were able to reap 13¼ cwt. of dry beans of some of the varieties per acre. This certainly gives promise that when proper spacing is adopted we shall reach a commercial yield under British conditions.

Other exotic crops that have done well at Woburn in 1949 have been serradella and birdsfoot trefoil, both suitable crops on semi-acid soils for fodder growing. The latter, grown from American seed, gave just under three tons of green fodder per acre on July 7th from seed sown near the end of April, while it has continued to grow and appears likely to give at least the same amount of fodder in 1950.

Pot Experiments

Clover sickness

We have been working at the question of the failure of clover to give a remunerative yield when grown too frequently on the same land, for a number of years, even in the absence of any known pathogen, and we have ventured to bring our results before one of the scientific societies during the past year. The cause of the failure is still undetermined, but we seem to be approaching a solution and we can perhaps summarize the present position here. Tests made over a number of years made it clear that even in the absence of clover rot fungus and the well known stem eelworm, clover growth became less and less in successive years if any of the usual varieties were grown year after year on the same soil. After growing clover for about five years in this manner, the soil became so clover sick that only tiny plants could be produced, and no known pathogen has been found which would account for the reduction in size.

We investigated the question as to whether the production of the sick condition in the land could be speeded up by increasing the temperature at which the clover is grown, by growing the plants under semi-waterlogged conditions, and by other methods. The only striking result has, however, been obtained by increasing the proportion of growing clover to soil, i.e. by growing as much clover as could be crowded into a pot, on very shallow soil. Under these conditions the soil becomes sick very much more quickly and this suggests the possibility that the clover itself leaves something in the soil which is inimical to further growth of clover.

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It quickly became evident that the addition of plant foods to the soil in the form of fertilizers would do little, if anything, to restore the healthy and proper growth of clover. This was found by Lawes and Gilbert nearly 100 years ago, and we can confirm their conclusions. They, however, state that if the soil contains large amounts of organic matter clover sickness does not appear nearly so soon as in other cases. Hence we tried the effect of addition of large amounts of farmyard manure to the sick soil and at once we obtained again a normal growth of clover. The effect did not last long, and on continuing to grow clover in succeeding years, the soil quickly reverted to the sick condition. Next we tried the effect of heating the soil in a moist condition to 70°C. for two hours, with the result that normal growth was again obtained though not quite up to the standard of fresh soil. This has been repeated several times, always with the same result. If the soil is heated in the dry condition, little effect is found. Other methods we have tried are (1) treatment of the soil with toluene to remove any active organisms. This gave no improvement of the clover on the sick soil, (2) treatment of the soil with formalin and then washing out the formalin with water. In this case slight but not very marked improvement was shown, but nothing like the growth on fresh soil was obtained; (3) the treatment of the soil with hydrogen peroxide so as to oxidize the more labile materials, and then washing out the reagent. In this case no improvement was reached. Negative results were also obtained when we tried to wash out any leachable materials from the soil, after which there was practically no improvement in clover growth, while the leachates applied to clover in healthy soil did little or nothing to bring about the dwarfing of the plants.

This is the stage at which the matter now rests. No definite pathogen has been identified which causes the condition here described, but its production can be intensified and quickened by increasing the proportion of clover to soil. The sick condition cannot be remedied by any addition of the ordinary plant foods to the soil, but can be temporarily got rid of by the addition of large amounts of farmyard manure or by heating the moist soil to 70°C. Washing the soil has no improving effect and the washings had no harmful effect on clover in fresh soil. Neither treating the soil with toluene nor partial oxidation with hydrogen peroxide did any good, while formalin had only a slight effect.

Competition of crop plants grown together

Starting as an investigation into the competitive power of several weeds with the barley crop, this work has been widened in the last two years into a study of the mutual effect of two crop plants usually grown together. In 1948 we studied the effect of barley and clover when grown together, and in 1949, the mutual effect of ryegrass and clover when laid down together, as is usual in an ordinary grass seed mixture. The results are now being worked up and promise to give results of distinct value. It is hoped to publish the results of the two years' work in the course of the next few months.

The nutrition of crops under very acid 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

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that represented by a pH value of 4·7 to 5·0. The special points that have been worked at in 1949 have been the relative effect of acidity (pH value), presence and absence of soluble phosphates in the soil, and the question of whether the actual amount of calcium present has any effect on the growth of the barley. The plan of the experiment enabled us to separate clearly the effect due to the several factors mentioned, and we are now working up the results with a view to early publication. It is clear, however, that while the dominant factor in the failure of barley on the very acid soil is the presence of something which can be precipitated by soluble phosphates even if these do not cause any reduction in acidity, there is a clear effect of calcium salts which do not raise the pH value. A still more striking result was obtained with lucerne, which was made to grow on soil at a pH value of 4·2 after the addition of sodium phosphate in large quantities.

Laboratory Work

Changes in the sulphur content of soils under long treatment with artificial and other manures

At Woburn we have land which has been under barley for nearly eighty years being treated with various manures every year, and from these plots samples of the soil have been taken from time to time at least during the first fifty years. In some quarters the changes in fertility have been attributed in some measure to changes in the available sulphur content of the soils. This matter has now been under investigation for several years and the work is now drawing to a close. It is hoped to complete it during the next few months.

Most of the time of the laboratory staff is usually taken up with the analyses, etc. in connection with the field and pot experiments. Most of this work falls on Mr. Barnes and his staff, together with the detailed carrying on of the pot experimental work.

At the end of the year, Mr. Barnes has also taken over a good deal of the recording of the field experiments, and has also become resident on the Station itself.

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