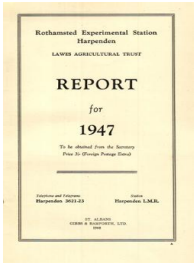
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Rothamsted Report for 1947

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DEPARTMENT OF PHYSICS

By R. K. SCHOFIELD

Shortly after his return from West Africa Dr. Keen went, at the request of the British Government, to East Africa to preside at an inter-territorial conference on agricultural problems and to advise on agricultural policy. He was appointed Director of the East African Agricultural and Forestry Research Organisation with effect from 1st August, 1947, since when Dr. Schofield has been in charge of the Physics Department.

FIELD WORK

Deep ploughing experiments

This series of experiments has continued to expand. Of the 15 experiments started on farms in 1944, 7 remained in experiment in 1947; of the 15 started in 1945, 12 remained in experiment; and 17 new experiments were started in the autumn of 1946 for the 1947 season. During 1947 arrangements have been made to start another 24 for the 1948 season; and all but one or two of the 36 fields under experiment in 1947 are expected to be under experiment in 1948.

These experiments are now situated in many counties of England and in two of Scotland, and the policy has been to ask the counties to undertake the actual responsibility for carrying out the experimental work on the fields. This Department remains responsible for the design, the choice of sites, and the working up of the results of all the experiments.

The results for the 1947 series have, in the main, followed the previous results. Thus, in spite of the opinions of many very successful growers, potato yields remain for the third year in succession unaffected by the depth of ploughing. For eight out of the nine comparable fields available this year the average yield on the 6–9 in. deep ploughing was 9·2 tons per acre, whilst it was 9·5 tons on the land ploughed to this depth and subsoiled and also on the land ploughed to 12-15 in. The corresponding figures for the average yields in the two previous years are 13·1, 13·0 and 13·1 tons per acre respectively. On the ninth field deep tillage appeared to increase the yield from between 1–4 tons per acre depending on the particular deep tillage treatment chosen for comparison, but the yields on different parts of the same plot were so variable that the precision of the experiment must be considered extremely low. The Rothamsted experiment again gave an increase of 0·7 tons per acre due to 12 in. ploughing compared to 6 in., making the average increase over the four years of the experiment 0·9 tons per acre. The result of this experiment thus continues to differ from those found elsewhere.

In 1947, as in 1946, deep ploughing either for wheat or for the previous crop may have increased yields by as much as 2–3 cwt. of grain. On one field on a very intractable silty clay it doubled the yield from 16–32 cwt. per acre compared with the normal ploughing of the farm. The soil on this field is typical of much of the silty soils of South-East England, and these lie in a region where deep ploughing is not practised at the present time. Deep ploughing

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had little effect on the yield of barley, whether done in the autumn for the crop or for the previous crop, although, again at Rothamsted, it increased the yield by about 2 cwt. per acre.

In 1947 the effect of depth of ploughing and of the time of application of the mineral fertiliser to sugar beet were examined in more detail than previously. The result shows that on the clay soils deep ploughing increased the yield of sugar beet by about 2 tons per acre compared with normal ploughing if the fertiliser was applied in the spring after autumn ploughing, but it had little effect on yield if the fertiliser was put on the land before autumn ploughing. Ploughing in the fertiliser in the autumn to 6–9 in. increased the yield by about 1 ton compared with putting it in the seedbed, as is the usual practice. However, on the deep ploughed plots, ploughing in the fertiliser tended to give a lower yield than applying it in the spring, probably because the seedbed of these plots, made out of subsoil, was too poor for the beet to start well.

On fields on sands and limestones deep ploughing had little effect on yield compared with shallow. But there was a tendency, both this year and last, for ploughing in the fertiliser in the autumn to give about half a ton of extra beet compared with applying it in the spring, whatever the depth of ploughing.

These deep ploughing experiments have now shown that, at least for sugar beet, they must include investigations on the response of the crop to different distributions of mineral fertiliser in the cultivated layer of the soil.

On the effect of inter-row cultivations on the growth of potatoes

The experiment has been continued for another year in which the effect of earthing up, of the depth of setting the hoes and grubbers used between the rows, and of mulching on the growth and the yield of potatoes. This year none of the treatments had any significant effect either on yield or on the proportion of potatoes greened.

METEOROLOGICAL WORK

Evaporation and transpiration

Observations have been continued, but no further analysis of data has been made as the main requirement at present is the collection of records over a period of some years to see if the earlier generalisations are valid. From the earlier work an attempt has been made to estimate transpiration losses from extended areas of grassland when rainfall is insufficient to keep soil moisture at a level high enough to maintain maximum transpiration rates. Using "field capacity" as an identifiable and reproducible reference level it is assumed that a moisture deficit is built up as transpiration exceeds rainfall, and that up to a limiting value, symbolised by C, transpiration rates are independent of the deficit. When the deficit exceeds C inches, soil factors limit water movement to the roots, and hence transpiration rates decrease. A quantitative expression of this falling off was obtained from earlier work on evaporation from bare soil. With knowledge of the time in spring when soil was at field capacity, of the succeeding weather, and of a value of C, it has been possible to follow the change in soil moisture deficit throughout the summer and autumn. Times of the first running of field drains on Cambridge University Farm have been

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successfully predicted within a few days, using values of C of about 3 in. This order of magnitude can be justified from the known rooting habit of the pasture, but further research will be needed to show how it depends on crop type, manuring, crop management, and spring weather.

The concept of soil moisture deficit, referred to above, has been presented in detail to show how it can give guidance in problems associated with soil mechanics.

Meteorological equipment

Attempts to improve equipment continue. The apparatus (referred to in the 1946 report) set up to measure dew-point continuously has not been very successful, but deficiencies in the recording instrument itself have been a contributory factor, and when certain faulty components are replaced the method will be given another test before a final verdict is reached. Apparatus has been built, and is undergoing laboratory trial, for continuous recording of transpiration so that variations during the day can be determined.

An exhaustive examination of the several rain gauges at the enclosure has revealed the sources of long standing discrepancies. These are partly due to exposure and partly due to a defective gauge glass in a new 5-in. gauge. A circular turf embankment has been built round one of our gauges, and this particular gauge will be used as the standard rain gauge in future.

During the year a standard pattern of evaporimeter has been set up to trace the source of discrepancies between open water evaporation, as measured by Meteorological Office pattern tanks, and our Rothamsted equipment.

Agricultural meteorology

A short article has been published on the nature of the physical and biological problems associated with agricultural meteorology, and some steps toward their solution have been taken in collaboration with the Entomology and Plant Pathology Departments.

With the former, a tower 105 ft. high has been set up, and the Physics Department has equipped it at two levels with continuous recorders for temperature, humidity and run-of-the-wind, with the dual purpose of providing the Entomology Department with contemporary physical data to link up with insect catches (aphides) and of supplying our own needs for more detailed knowledge of temperature, vapour pressure and wind velocity profiles in connection with evaporation and transpiration studies. Preliminary surveys indicate that the first purpose has been successfully achieved; as indicated above, no detailed analysis for the second purpose has yet been attempted.

For the Plant Pathology Department a small portable general purpose field unit has been designed and built to measure the same three weather elements in the restricted space available inside growing potato crops. The instrument is based on the very large negative temperature coefficient of electrical resistance of semi-conducting elements known as "thermistors". From the point of view of both Departments the year's work has been exploratory, and successfully so. In the light of experience gained a new instrument is being built which will be simpler to use and more

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precise. Judging by visitors' interest a satisfactory instrument of this kind will meet a real need.

At the request of a joint sub-committee of the Meteorological, Entomological and Ecological Societies Dr. Penman is writing a book on the meteorological principles and methods of importance in the study of the effect of weather on biological activity.

Laboratory work

Physico-chemical studies

The review on p. 95 covers those sections of the physico-chemical studies which have been under investigation for a number of years. There remains for mention here a new investigation on the migration of ions through soil and other porous materials. This investigation has two objects. In the first place it should throw light on the factors controlling the rate of movement of nutrient ions towards the plant root. In the second place, since the migration must take place through water, these studies may throw light on the condition of the water in the minute interstices of the soil. The investigation has already brought to light an interesting effect when bentonite is added to a salt solution. The conductivity of N/10 potassium bromide solution is reduced 16 per cent. by adding 0·91 per cent. of a very fine bentonite which, under these conditions, forms a thixotropic gel, whereas the conductivity of N/40 potassium bromide is increased 3 per cent. by adding 0·57 per cent. of the same bentonite which in this case forms a deflocculated suspension devoid of rigidity. These bentonite particles are plates 10 A. thick.

These results strongly support the view that the bentonite particles in a thixotropic gel form a kind of network in which the edges of neighbouring particles are drawn towards each other.

Vapour pressure of solutions

The work on vapour pressure of solutions was first undertaken in order to supply information to the Bee Department about the relationship of the aqueous vapour pressure of honey to its water content. Some measurements were made using pure glucose and fructose and the question arose as to how the results should be set out. A study of the literature shows that no convenient method had been devised for expressing the departure of very concentrated solutions of non-electrolytes from ideal behaviour. Since there is an obvious analogy between the behaviour of water in a concentrated solution and water in moist soil, the problem has been examined in a more general way. We have hit upon a new handling of vapour pressure data, and a paper on this subject is in course of preparation.

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DEPARTMENT OF CHEMISTRY

By E. M. CROWTHER

Several series of investigations involve related work in field, pot and laboratory experiments. A number of investigations on the manuring of sugar beet and peas, the use of various kinds of bulky organic manures and phosphate fertilisers were continued on similar lines to those described in the 1946 report and are not discussed here. A good deal of time was devoted to tests on new or local forms of fertiliser and to the design and analysis of results of experiments on soil fertility questions carried out by Ministry of Agriculture and the Colonial services. Much of the work was carried out as team work by several members of the Chemistry Department, often in collaboration with members of other Departments.

FERTILISER PLACEMENT

Field experiments on potatoes in the United States have shown that fertiliser placed in bands beside the sets is more effective than the same quantity of fertiliser broadcast and worked into the soil before planting. It would not, however, be safe to apply the results of the American work directly to British practice because there are many important differences between the methods of planting potatoes in the two countries. Many of the American experiments were on cut sets planted mechanically but in Britain it is customary to broadcast fertiliser over drawn-out ridges before planting whole sets. The British method automatically ensures good "fertiliser placement" and there may be little advantage in using special machines to place the fertiliser in definite positions.

In 1945 an investigation was commenced under the aegis of a Conference of the Agricultural Research Council to test alternative methods of applying fertiliser to potatoes grown in ridges.

Fertiliser dispensing mechanisms used on commercial drills are not accurate enough for experimental work on alternative methods of applying prescribed amounts of fertiliser; the delivery rate for a given setting varies with the condition of the fertiliser and the atmospheric humidity. The National Institute of Agricultural Engineering, therefore, built a special experimental fertiliser placement machine to overcome this difficulty by using a positive displacement mechanism. Fertiliser is contained in a cylinder fitted with a rising piston which pushes the fertiliser out of the top of the cylinder where it is dispensed to tubes feeding adjustable coulters in the soil. Studies of this machine over two seasons showed that it could be relied upon to deliver a definite volume of fertiliser for a given distance travelled. Changes in the density of the fertiliser caused by alterations in atmospheric humidity did not cause sufficiently great changes in delivery rates to affect the accuracy of the field experiments.

In four preliminary experiments in Hertfordshire in 1945 there were only small differences between broadcasting a compound potato fertiliser over the ridges or placing it in contact with the seed, in a single band 2 in. below the seed or in two bands, 2 in. below and 2 in. on either side of the seed. At one centre very

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deficient in phosphate there was some advantage at low rates of manuring from placing the fertiliser in contact with the seed.

During 1946 and 1947 25 experiments were carried out in some of the important potato-growing areas of Eastern England to test two methods of broadcasting—(a) on the plot before ridging (b) after ridging but before planting—against two methods of placement—(c) in contact with the sets (d) in two side bands 2 in. below and 2 in. to the side of the sets. A National Compound Fertiliser (7% N, 8% P_2O_5, 10·5% K_2O) was used at three rates, 5, 10 and 15 cwt. per acre, by each method. The mean increases calculated for the average dressing of 10 cwt. fertiliser per acre were:

Increase in yield of potatoes, tons per acre

		Broadcast		*Placement*		
	Experiments	Before ridging	After ridging	Contact	Side-bands	
1946	15	2·5	3·3	3·4	3·2	±0·17
1947	10	1·7	2·1	1·9	2·1	±0·15
1946 & 1947	25	2·2	2·8	2·8	2·8	±0·11

On the average of both seasons broadcasting after ridging and before planting was significantly better than broadcasting before ridging. The two methods of controlled placement by the experimental machine gave results very similar to those by broadcasting after ridging. From the response curves for increasing amounts of fertiliser the general conclusion can be drawn that 7 cwt. of compound fertiliser applied after ridging will give the same average yield as 10 cwt. of the fertiliser broadcast before ridging. Farmers who still apply their fertiliser before ridging would be well advised to follow the practice more common among specialist growers of applying fertilisers after ridging. So long as ridges are drawn there is little need for special machines to provide controlled placement; if mechanical planters working on the flat are to be used, broadcasting fertiliser before planting may be inefficient and some attachment will be needed to place fertilisers near the sets but not so close as to risk damage in dry seasons.

In 1945 and 1946 there were no checks to early development from heavy dressings of fertiliser in contact with the sets; in the long dry spell from mid-May to the end of June, 1947, 15 cwt. of fertiliser per acre in contact with the seed retarded early development at several centres, though the crops recovered after heavy rain at the end of June.

During 1947 preliminary experiments on fertiliser placement for row crops—sugar beet, mangolds, swedes and peas—were carried out with a special experimental drill built by the National Institute of Agricultural Engineering again using a top-delivery fertiliser mechanism. At a number of centres fertilisers placed in bands below the seed, either immediately below or a little to the side, gave much better yields than fertilisers broadcast. During the extremely dry season of 1947 much of the broadcast fertiliser must have remained uselessly in the top inch or so of dry soil. The experiments showed the danger of placing fertilisers with a high proportion of soluble salts close to the seeds of root crops, as e.g. by drilling fertiliser with the seed. In several experiments 4·5 cwt.

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of National Compound No. 2 per acre placed in contact with the seed killed the plants, but the same amount placed to the side of the seed gave a good stand.

Sugar beet manuring and soil analysis

The standard series of manuring experiments testing N, P, K, Na and B fertilisers was carried out again in 1947 with at least one experiment in each factory area and there was also a smaller series on forms of nitrogen fertiliser.

The responses of sugar beet to superphosphate on 216 non-calcareous mineral soils and to potash on 248 mineral soils over the years 1936 to 1946 were examined in relation to the results of a number of analytical methods for soil samples taken from the experimental sites immediately before the fertilisers were applied in the standard series of experiments. The value of the analytical methods was assessed by evaluating the average profit (at 1946 prices) that would have accrued over the whole area represented by the experiments if certain centres had been selected for manuring by means of each analytical method in turn—the other centres being unmanured—and comparing this profit with what would have been obtained if the same total quantity of superphosphate or muriate of potash had been divided evenly over all the centres.

Only about one-quarter of the soils gave highly profitable responses to superphosphate. If one-quarter had been picked by the citric acid method as the most phosphate-deficient and given superphosphate at the rate of 1·0 cwt. P_2O_5 per acre the average profit over the whole series would have been equivalent to 0·62 cwt. of sugar per acre as compared with 0·39 cwt. of sugar per acre if the same total quantities of superphosphate had been spread over the whole of the centres at the rate of 0·25 cwt. P_2O_5 per acre. The immediate profit from superphosphate would have been increase by over one-half by using soil analysis.

The responses to potash were more general and there was therefore less opportunity for economy by omitting potash. If five-eighths of the centres chosen by the citric acid method had received 0·6 cwt. K_2O per acre, the average profit over the whole series would have been 1·57 cwt. sugar per acre as compared with 1·23 cwt. sugar per acre from distributing the same total amount of potash evenly over all centres.

There were only small differences in value between the principal recognised methods of analysis. It was possible from such investigations to improve analytical methods by prescribing the conditions under which they should be used and by changing the limits in accordance with other soil characters. Thus the citric acid method for phosphate may fail on very acid soils. For potash it gives better results if lower limits are used for heavy soils.

Salt for sugar beet

During 1944–6, 30 experiments were carried out on commercial farms to test different times and methods of applying agricultural salt. The results show that nothing would be lost by spreading the salt at a less busy time in winter. It is just as good to distribute the salt on firm land before the winter ploughing as to apply it

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broadcast to the ploughed land either in winter or in spring. Salt should be used in such a way and at such a time as will get it well down into the soil.

Mean increase in sugar, cwt. per acre

	No. of trials	Mean of 3 and 6 cwt. salt per acre: Winter ploughed in	Winter broadcast	Spring broadcast	Mean of times: 3 cwt. salt	6 cwt. salt
1944	14	3·4	3·4	3·9	3·5	3·5
1945	9	4·6	3·9	4·3	4·1	4·5
1946	7	3·5	4·1	2·0	2·2	4·3
All years	30	3·8	3·7	3·2	3·2	3·9

NUTRITION PROBLEMS IN FOREST NURSERIES

First year seedlings of Sitka spruce and Scots pine raised in 1946 at Wareham, Dorset, on heathland soil carrying its first crop of conifer seedlings and treated with fertilisers gave good establishment and growth when tested in 1947 as transplants in several nurseries or when planted directly into three forests. The extremely dry conditions of 1947 restricted growth in many experiments and provided a good test for possible damage to seedlings from fertiliser salts; none was found. Although responses to nitrogen fertilisers were frequently poor, ammonium sulphate gave excellent results at two nurseries when used as top-dressings on watered plots; on several plots at each nursery the mean heights of Sitka spruce exceeded 3·0 in. Neither watering alone nor nitrogen fertiliser alone gave much improvement.

In several nurseries on heathland or forest sites there were very large benefits from superphosphate, which sometimes proved markedly better than basic slag or mineral phosphate. Superphosphate does not appear to have been tested previously in forest nurseries in this country, and recent demonstrations of its special value may prepare the way for a more general application in forest nurseries of methods of manuring developed in agriculture and horticulture. Seedlings or transplants grown with either composts, fertilisers or both gave no evidence in size and subsequent growth that the composts exerted any effect beyond supplying available nutrients. There have been several cases in which individual kinds of compost have been relatively deficient in one or other of the major plant nutrients. Many experiments are being made to test whether there are any long-term differences in the subsequent behaviour of the trees when planted in forests.

Several nurseries with neutral or calcareous soils gave particularly poor Sitka spruce and Scots pine seedlings in 1947. Treating the soil with either acid or formalin gave some improvement, but the treated soils failed to produce large plants. The precise cause of the failure has still to be determined, but some indication of a "lime-induced chlorosis" was obtained when it was found in 1947 that a local failure of conifers in a calcareous corner of an otherwise acid nursery was matched by a parallel failure of yellow lupins with equally good growth of both conifers and lupins in the acid parts of the nursery. It was found during 1947 that a number of established nurseries in which conifer seedlings grow badly had

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high pH values as the result of lime, limestone or other basic materials used in manures for green crops, in composts or in calcareous seed covers. The characteristic failure of conifers on some of these soils was reproduced in pot experiments on Sitka spruce grown in mixtures of soil and acid-washed flint.

Spectrographic analysis

In the course of a large number of plant analyses by the Lundegardh flame spectrographic method, a series of crop samples was examined from an old liming experiment at Oaklands, St. Albans. This experiment was laid down in 1933 as a 5×5 Latin Square with increasing dressings of chalk. In 1946 the pH values ranged from 4·3 to 6·5. Samples of wheat taken on five occasions during 1946 showed that liming had very little effect on the concentration of calcium within the plant, but that liming had increased the concentration of magnesium and decreased that of manganese. Analyses of peas, beans, oats and barley grown on the same plots in 1945 led to the same conclusions. Rye grass and clover hay in 1947 had high calcium contents on the limed plots, but the increase in calcium was due to the higher proportions of clovers which are rich in calcium. The individual species, like the wheat and the other crops examined in previous years, showed very little effect of liming on the actual concentration of calcium within the plant.

Analyses on plants from cereal variety trials in Hertfordshire showed a higher concentration of manganese in the roots than in the tops of the plants, but the possibility of soil contamination renders the conclusion somewhat uncertain.

A number of Broadbalk soils have been analysed and a method developed for studying the ion-concentration of the soil solution.

The basic calcium phosphates

In a study of precipitated calcium phosphates over the range between the well-known materials dicalcium phosphate and hydroxyapatite $Ca_5OH(PO_4)_3$, there was no evidence of the formation of tricalcium phosphate $Ca_3(PO_4)_2$ as a definite compound. In a continuous series of solid solutions this particular composition merely marks the stage at which further uptake of calcium must be accompanied by the entry of OH (or F) ions. Precipitates of a composition represented by $Ca_4H(PO_4)_3$ were repeatedly encountered in the course of the work. They were shown to have an apatite-like structure but they also had X-ray diffraction lines indicating a sheet-like structure. Similar precipitates were described long ago by R. Warington, under the name "octo-phosphate" but they have rarely been mentioned in later work. It appears that "octo-phosphate" forms a continuous series of solid solutions with increasing amounts of calcium up to hydroxyapatite.

Some of the anomalies in the potentiometric titration curve of phosphoric acid and calcium hydroxide, the apparent weakness of dicalcium phosphate as an electrolyte, and discrepancies between experimental pH values and those calculated from the concentrations of calcium and phosphate and the dissociation constants of phosphoric acid, could be reconciled by the assumption that some such complex ion as $CaPO_4$ is present.

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Soil manganese

Work on the various forms of manganese in soils was continued in collaboration with the Biochemistry Department with special reference to organic soils. Earlier work by Dion and Mann had shown that neutral pyrophosphate extracts of mineral soils contain mainly trivalent manganese. It was found that alkaline (pH 9·3) extracts of mineral soils and both neutral and alkaline extracts of fen soils contain divalent manganese. When mineral soils poor in organic matter and rich in the higher oxides of manganese are extracted with neutral pyrophosphate containing manganous sulphate, the added manganese reacts with the higher oxides to yield more soluble manganese (reverse dismutation). Under similar conditions fen soils retained large amounts of the added manganese in a form which within a few hours ceased to be readily exchangeable with ammonium acetate, but could be recovered by extraction with alkaline pyrophosphate solution. Manganese salts added to fen soils either alone or with ammonium acetate behaved in the same way as those added in neutral pyrophosphate solutions. In experiments on a number of salts it was found that Cd^{++}, Ni^{++}, and Cu^{++} were particularly effective in preventing the uptake of added manganese and in recovering the manganese held in other than readily exchangeable forms by fen soils. The same cations also increased the amount of manganese extracted from neutral organic soils containing little exchangeable manganese, though the high values obtained with ammonium acetate containing copper may have been due in part to a reduction of higher oxides of manganese in the presence of copper salts and organic matter.

Some fractionation of the complexes between metal and organic matter could be obtained by pretreating the soil with sodium chloride and then, in turn, with water, pyrophosphate solution and 2 per cent. sodium hydroxide. Manganese and copper retained by soils in forms not exchangeable for sodium could be recovered subsequently in the water or pyrophosphate extracts. It appeared that the manganese and copper in the water extracts remained combined with organic matter as in the soil itself.

Soil iron

Iron compounds appear to react with soil organic matter in two ways. The iron may enter the exchange position to form a material which may be described as a "basic ferric humate". Such iron can be extracted only by acids or salts capable of forming complex ions with iron. Iron may also react with amino and hydroxy or similar groups in soil organic matter to form a complex which can be extracted when soil, previously washed with a hydroxyacid, is saturated with sodium and then extracted with water. Iron present in organic complexes is left behind when sodium pyrophosphate extracts of soils are dialysed against running water.

Soil organic matter

As soil organic matter is oxidised and degraded when treated with caustic alkali, an attempt was made to find alternative extractants less likely to alter the physiochemical properties of the organic complexes. The solubility of soil organic matter is largely determined by the nature and extent of its association with metals. The efficiency of neutral salt extractants appears to depend on the

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ability of the anion to remove interfering metals either as insoluble precipitates or as soluble coordination complexes. It is well known that cations other than sodium, potassium and ammonium precipitate organic matter, and that calcium interferes with the extraction of organic matter. Neutral sodium pyrophosphate was found to be particularly effective for extracting organic matter from soils; the optimal conditions for this extraction were worked out.

An attempt was made to determine the forms in which organic nitrogen occurs in soils and, in particular, to establish whether or not the major part of soil nitrogen is present in the form of protein. Proteins as such could not be isolated from soil, but a considerable fraction of the nitrogen in soil hydrolysates was found to be present as α amino-acids. By determining the α amino-acid contents of various soil hydrolysates it has been shown that at least 30 to 40 per cent. of the total nitrogen in the soils examined was in some form of protein-like combination. There was some evidence that some of the organic nitrogen of soils occurs as amino-sugars.

Nitrogen contents of Broadbalk soils

A systematic survey of the chemical changes in the soils from the long-continued cropping and manuring experiments at Rothamsted is in progress. The following summary of changes over 80 years of almost continuous wheat growing is given for some of the principal plots in Broadbalk field. The plots were fallowed every fifth year from 1925.

Nitrogen percentages of Broadbalk soils, first 9 inches, passing 2mm. sieve

Annual Manuring	3 None	5 PK	7 NPK	2A Farmyard manure from 1885	2B Farmyard manure from 1843
1865	0·105	0·106	0·117	—	0·175
1881	0·101	0·107	0·121	—	0·184
1893	0·094	0·101	0·115	0·136	0·213
1914	0·093	0·103	0·115	0·191	0·251
1936	0·103	0·105	0·120	0·186	0·226
1945	0·105	0·106	0·123	0·194	0·236

The 1945 samples were taken from a large number of holes on each plot, the earlier ones from only a few holes often dug to considerable depth. There can be little doubt that the high value for plot 2B in 1914 was fortuitous, as the two samples concerned were highly discordant, probably through the inclusion of manure in one of the samples (0·266 and 0·236 per cent.).

Plots without farmyard manure appear to have reached substantial equilibrium within 20 years of the beginning of the experiment. The slight fall on the unmanured plot up to 1914 was made good more recently. On the plots with farmyard manure annually the nitrogen percentages rose steadily for about 50 years and then changed but slowly. It would be expected that fallowing every fifth year would check the accumulation of soil organic matter, because no organic matter is added in the fallow year either as manure or plant roots, and residues from recent applications would be rapidly oxidised. On the plots without

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farmyard manure the nitrogen contents increased slightly after fallowing was introduced, probably as the result of the much better crops grown in the year immediately following the fallows.

Analytical methods

Particular attention was given to the development of rapid methods in analysing soils for readily soluble plant nutrients, the determination of fluorine in soils and of nitrates in soils and composts. A paper on a semi-micro method for determining carbon in soils was read to the Society of Public Analysts and other Analytical Chemists.

Methods for fertiliser experiments

For the guidance of agricultural workers in the colonies a memorandum was prepared describing some of the methods of field experimentation which had proved their value in recent manurial and soil fertility investigations in Britain.

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DEPARTMENT OF SOIL MICROBIOLOGY

By H. G. Thornton

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

A. Work dealing with the Soil Micropopulation

(1) *The effect of soil micro-organisms on soil structure*

Rapid improvement in the crumb structure of soil can be brought about by incorporating suitable organic matter containing readily decomposable substances. This effect is produced scarcely at all by relatively resistant materials such as well rotted farmyard manure or compost. Mr. R. J. Swaby has isolated a variety of micro-organisms from soil to which readily decomposable organic materials had been added and has tested the effect on soil crumb structure of these organisms in pure culture and in mixtures of pure cultures. The greatest as well as the most stable improvement in soil structure was produced by soil fungal mycelium. Actinomycete mycelium produced less stable aggregates, while a very small and temporary effect was produced by cultures of bacteria that produce gums. Mixed cultures containing fungi were usually more effective than mixtures of actinomycetes, yeasts or bacteria, but micro-organisms in some of the mixtures tested were found to antagonise each other with reduced effect on structure. Soil fungi also improved the structure better than did a soil suspension containing a great variety of micro-organisms. The soil crumbs produced by micro-organisms are short-lived, even those produced by fungi breaking down if bacteria or other organisms capable of attacking fungal cell walls are also present.

The more permanent soil crumbs found in some soils such as chernozems, rendzinas, krasnozems and terra rossas, cannot be fully explained as direct effects of micro-organisms. The more resistant humus seems to play a part here and an attempt is being made to determine which of the humate fractions are mainly responsible.

(2) *Nitrifying bacteria*

Dr. Jane Meiklejohn in a study of the bacteriology of ammonia and nitrite oxidation has devised an improved culture medium for use in nitrification studies and has investigated the effect of trace elements on the nitrifying activities of crude liquid cultures. This work, carried out with the co-operation of Dr. H. Lees of the Biochemistry Department, showed that iron markedly stimulated the production of nitrite from ammonium salts. A mixture of 10 trace elements lacking iron, copper and zinc was found to depress nitrite formation; this depression was prevented by the further addition of iron or copper but not by zinc. A proper balance of minor elements hence appears important to the nitrification process.

(3) *Micro-organisms attacking resinous substances in soil*

Mr. P. C. T. Jones concluded his researches on microbial decomposition of "Vinsol" and "Gum rosin" in compacted soil,

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work undertaken on behalf of the Road Research Board, by investigating the stabilising action of various antiseptics added with the resins to the soil.

(4) *Soil actinomycetes*

Mr. F. A. Skinner commenced work here in August and is investigating the actinomycete flora of some Broadbalk plots comparing the flora of the wheat root surface with that of the main soil mass. This work is in its early stages.

(5) *Mycorrhizal associations*

Dr. Janet Mollison, who also commenced work here in August, has continued her investigation of mycorrhizal associations, particularly in clover and wheat roots. Her earlier work established that red and white clover plants growing in the field are always infected with a Phycomycete fungus that forms typical root associations of the "endomycorrhizal" type. A similar fungus has also been found in wheat roots and a survey is at present being undertaken of the relative abundance of mycorrhizal infections on wheat roots from variously manured plots of Broadbalk in samples taken at regular intervals. This is being carried out in conjunction with estimates of the content of fungal mycelium in these soils.

Experiments to test the comparative growth of clover with and without the Phycomycete and to study the conditions determining infection and emergence from the root are under way.

(6) *Myxobacteria*

The numbers of this group that attack true bacteria by means of antibiotic secretions are of special interest in connection with the competition between sections of the soil population. Knowledge as to their distribution in soils was wholly lacking until Dr. B. N. Singh made a survey of their distribution in Rothamsted plots and in soil samples from a wide area in Britain. He is now extending this survey to soils obtained from other parts of the world.

(7) *Protozoa.* (a) *Giant rhizopods*

Dr. B. N. Singh has continued the study of the life history and feeding habits of the giant Rhizopod, *Leptomyxa* Goodey, which he has found to be abundant in arable soil. Its development in soil under laboratory conditions is unaffected by reaction over a range fram pH 4·2 to 8·7 nor is its distribution in field soils related to their reaction. The organism is specific in its bacterial food requirements and was found to eat rather less than half of the 92 species of bacteria supplied to it in a test. It differs markedly in its preference for particular bacterial species both from true soil amoebae and from the amoebula stage of Acrasieae, but it resembles these in its dislike for bacteria that produce pigments other than yellow or orange and in its indifference to the gramstaining reaction of the bacteria.

A single individual Leptomyxa contains a large number of nuclei which undergo simultaneous division by an unusual form of mitosis in which the nuclear membrane and the nucleolus persist until telophase. The organism produces multinuclear cysts in a manner unique amongst protozoa but resembling the sclerotium formation in Myxomycetes. This formation of cysts is dependent

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both on the cultural conditions and the species of bacteria supplied as food. Of 65 strains of bacteria edible to it only 20 led to the production of cysts in any considerable numbers.

(7) *Protozoa.* (b) *Effect of bacterial food on the life cycle of soil amoebae*

The part taken by active amoebae in consuming bacteria in the soil makes it important to understand the effect of the type of bacterial food on the growth of amoebae. Dr. B. N. Singh has found in previous work that certain species of bacteria are readily eaten while others are inedible to soil amoebae. Miss L. M. Crump has found that such amoebae can be trained to feed and multiply normally on a species of bacterium that was at first almost inedible to them. When fed on a pure bacterial culture whether originally edible or not the amoebae tend to lose the ability to form cysts.

(B) Investigation concerning the Nodule Bacteria of Clover

(1) *Stability of bacterial strains as regards effectivity*

The tendency for strains of the nocule bacteria to change their effectivity towards the clover plant in certain soils (see previous reports) is of great importance affecting the chances of improving clover growth by inoculation. Dr. J. Kleczkowska is investigating the problem of strain stability along two lines.

First, the tendency to produce ineffective mutants in soil is being investigated by using a strain known to be liable to change and growing this in a variety of soils in the hope of discovering the soil conditions producing the change, and also by growing a number of bacterial strains in a soil known to produce changes in some strains, in the hope of discovering a genetically stable strain. This investigation is still in progress.

Secondly, the known tendency for bacteriophage to induce the appearance of mutant forms of the bacteria differing from the parent strain in effectivity is being studied. Three bacterial strains originally ineffective towards clover were subjected to the action of 'phage. With one of these strains the 'phage failed to produce mutants differing in effectivity from the parent strain. In a second case effective and intermediate mutant strains appeared and retained their new characters after isolation and purification by plating and plant passage.

In the third case effective and intermediate mutants were obtained but repeated plating from single colonies always produced a mixture of isolates differing in effectivity, about 60 per cent. of them being ineffective. This result indicates that strains differ greatly in their stability as regards their effect on clover.

(2) *The ability of bacterial strains to establish themselves in the field*

Success in the commercial "inoculation" of legume crops clearly depends first on the ability of the bacteria used as the inoculum to become established in the soil and produce an adequate number of nodules in the crop. Where inoculation is used to replace "wild" strains of nodule bacteria that are ineffective towards the crop, by an introduced effective strain, it is necessary to use for inoculation a bacterial strain able to establish itself in

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competition with the wild strains already present in the soil. Miss Margaret Thomas is investigating the ability of selected effective strains of bacteria to produce nodules on clover inoculated with them under field conditions. Trials have been run at half a dozen centres. These involve the isolation of bacteria from an adequate number of nodules from inoculated and untreated plots and serological identification to determine the percentage of nodules in the treated plots that were produced by the inoculum. This work is still in progress.

(3) *Genetics of clover in relation to nodule formation*

Further work by Dr. P. S. Nutman in the inheritance of resistance to nodule formation suggests that the production of the cytoplasmic factor considered to be responsible for the maternal component in the inheritance is itself determined by the recessive resistant factor *r*. More than one simple resistant factor has been identified in material of different origin.

Grafting experiments with resistant and susceptible plants have shown that the resistance of the root system is independent of the genetic constitution of the scion.

Studies in the inheritance of the effectivity response have been continued.

(4) *The physiology of nodule production*

An examination has been made by Dr. P. S. Nutman of the influence of delayed inoculation on nodule formation. With effective strains moderate delay leads to an enhanced rate of nodulation but further delay to a reduced rate, but following delayed inoculation with ineffective strains no increase in rate is evident. This result is consistent with the theory that the early formation of effective nodules results in the secretion into the neighbouring tissues of a substance inhibitory to the formation of other nodules or of lateral roots nearby, but that ineffective nodules degenerate before this substance can be produced. Further experiments to test this hypothesis are in progress.

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DEPARTMENT OF PEDOLOGY

By A. Muir

The work being done in the Pedology Department falls roughly into four sections: weathering of rocks and minerals, clay mineral studies, spectrographic analyses, and chemical investigations. In connection with the development of the spectrographic work the Department has been fortunate in obtaining the assistance of Prof. R. Mannkopff and Mr. H. Albrecht of Gottingen who are designing and building new apparatus.

The Soil Survey of England and Wales shares the Pedology laboratories and one or two members of the Soil Survey are collaborating in the clay mineral researches.

Weathering of rocks and minerals

A study of the weathering of the rocks of the Malvern Hills begun some years ago in the Chemistry Department and stopped during the war has been restarted in this department, the whole suite of rocks and soils having been resampled. The work includes not only the bulk changes in the rocks during weathering, but also the alteration in individual minerals and will relate these changes to the development of the soil profile. The soils of the Malverns are in general shallow and excessively drained, but there has been little or no glaciation and soils which are truly "in situ" can readily be found. In composition the rocks range from granite to appinite, a fairly basic rock, and masses of rock rich in biotite offer a good opportunity for weathering studies.

Clay mineral studies

Work which was started at Aberdeen on clay mineral complexes with organic liquids was continued in 1946. Facilities for X-ray work were kindly provided by Dr. C. A. Beevers at the Dewar Crystallographic Laboratory, Edinburgh, in the absence of suitable facilities in the Department. The results of this work have now appeared in the Trans. Faraday Soc.

In 1947 two X-ray sets were installed. One is a standard Metropolitan Vickers crystallographic unit. The other is a modification of an existing Shearer type gas tube. Power cameras of two sizes (90 and 57·4 mm.) have been designed and made for these two sets, which are now in operation.

A number of X-ray photographs of clays from Scottish podzols, which were taken at the Macaulay Institute for Soil Research, have been interpreted and the results have formed the substance of a communication to the Congress of the C.O.B.E.A. (Comité Belge pour l'Etude des Argiles) in May, 1947. This is in course of publication in "Verre et Silicates Industriels". The main results of this research are (a) the alteration of the micaceous minerals in the clay fraction, on passing up the profile, has been traced. Emphasis is laid on the progressive alteration of chlorite and biotite mica. (b) The effect of the presence of free sesquioxides in the B layer on the X-ray diagram has been traced. (c) Stress is laid,

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in general, on the importance in soil clay work of studying the clay from a number of horizons of the profile so as to get an idea of their inter-relation.

A theory of the free energy relations in clay mineral complexes has been developed, based on Bangham's adsorption measurements on mica, and has been presented to a meeting of the British Rheologists Club.

A number of clay minerals are now being fractionated with the supercentrifuge as a preliminary to doing research on fixation of ions by pure clay minerals.

Work on the adsorption of organic liquids by montmorillonite and halloysite has been extended to nitriles and a beginning has been made in the determination of adsorption isotherms from solutions of organic liquids with montmorillonite. In the latter study acetone in cyclohexane has been used but the existing methods for the determination of acetone have not proved very satisfactory under the conditions of the experiment.

Spectrographic analysis

Since the laboratories only became available in the latter part of the year the main work has been the installation and testing of equipment which includes a large (Littrow) and a medium Hilger spectrograph with ancillary apparatus. Prof. Mannkopff has designed a spectrograph with glass optics and fully automatic. This with other equipment is under construction in the Station workshop.

Gleying in soils

With a view to elucidating the mechanism of gleying in soils the problem of the stabilisation of ferrous iron by various means is being studied.

As the first stage in this work the oxidation of iron under various conditions is being investigated. It seems to be established that the readiness with which atmospheric oxygen will oxidise ferrous iron is a function of the degree of ionisation of the ferrous compound. Dilute (0·1N) solutions of ferrous salts under weakly acid conditions have been shown to be remarkably stable to atmospheric oxidation. The rate of oxidation is increased markedly, however, if the ionisation of the ferrous salt is decreased in various ways. Work is in hand to develop a quantitative relationship between the rate of oxidation and degree of ionisation. It is intended to continue this work by studying the oxidation of ferrous-organic and inorganic complexes. It seems that previous work on ferrous-organic complexes needs repeating.

Work has been started on iron-clay systems. It is intended to investigate the oxidation-reduction characteristics of these systems.

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DEPARTMENT OF BOTANY

By WINIFRED E. BRENCHLEY

During the year 1947 no fresh line of investigation was opened up in the Department, but attention was concentrated on consolidating the results of the work in hand, and filling up the gaps in the information required by supplementary experiments. As in previous years, the long-term classical work on Park Grass and on the dormancy of buried weed seeds received due attention. On the physiological side the part played by minor elements in plant development and the influence of certain environmental conditions on growth provided abundant material for pot and water culture experiments.

A. MINOR ELEMENTS

All over the world the part played by molybdenum in the plant economy continues to elude observers, the results being so variable even under apparently similar conditions that it is still not possible to give a definite answer, as can be done with boron.

(a) *Soil cultures*

Earlier work had shown that the relative toxicity of molybdenum to plants varies with the soil, and also that the reaction of different crops varies considerably in the same soil with similar molybdenum treatments. The growth of *flax* was greatly impeded on a manganese deficient Fen soil, and the molybdenum toxicity was masked in consequence, becoming more evident where a dressing of manganese sulphate had also been given.

In 1947 sowing was greatly delayed because of the difficulty in obtaining the soil owing to the severe winter and the flooding in the Fens. Again the characteristic habit of growth in flax appeared on the Fen soil, but where the main stems died most of the basal shoots grew vigorously, giving a short bushy plant, in striking contrast to the tall unbranched stems on the Woburn soil. Little seed was formed, though the quantity was higher where manganese was added. The development of the basal shoots delayed maturity very considerably, and when cut the plants were still green, though they were allowed to grow for six weeks after the Woburn plants had been harvested, when fully ripe with abundant seed.

An additional heavy dose of sodium molybdate was tested, giving a further reduction of crop. The seasonal effect was very marked, as the yield throughout was higher than in the previous years and the toxic effect of molybdenum was less drastic. On the sandy Woburn soil the lowest dressing of molybdate again had no poisonous effect, and the reduction of yield with greater amounts was less severe than on the Fen soil. It is hoped that at a later date the fibre will be extracted from this year's crop for comparison with that of earlier years.

Mustard showed considerable individuality in its response to molybdenum poisoning. Frequently one or two of the three plants

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per pot were killed or seriously stunted, while the others were very similar in size and appearance to those in the control pots without molybdenum.

The acid Waterbeach Fen soil was the most harmful to growth, apart from any molybdenum dressing, and the manganese deficient Isleham Fen soil allowed as good development as several of the others. The addition of manganese pushed up the dry weight in this Fen soil above that of the controls in any of the others. The lowest dressing of molybdenum was ineffective in most cases, except on ordinary loam with and without peat, but increasing doses reduced growth in varying degrees according to the soil. The most serious toxicity occurred on the loams, and the Isleham Fen without added manganese, the crops being only from one-quarter to one-tenth that of the corresponding control. On the other soils as much as one-half to two-thirds of the control dry weight was achieved even with the heaviest dose of sodium molybdate.

Red Clover was sown in the same soils as the flax, and in similar small glazed pots. Two cuttings have already been made and the crop is being overwintered, so that only preliminary statements can be made as to the ultimate effect of the molybdenum dressings.

In the earlier weeks of the experiment the addition of manganese to the Isleham Fen soil again caused much improvement in growth, and mitigated the harmful effect of the higher dressings of molybdenum. In the autumn, after all the molybdenum had been applied and an extra dressing of basal fertiliser had been given a striking response was noted in the Isleham Fen soil without added manganese. Here the pots receiving the lowest dose of molybdenum were growing well, being dark green and healthy, whereas the controls were small, poor and chlorotic, those with the medium dose of molybdenum being similar to the controls, but rather greener. This development is being closely watched to see if it reflects an interaction between manganese and molybdenum.

(b) *Nutrient solutions*

Much of the work in nutrient solutions was hindered by the unusually hot summer. Two large sets of lettuce bolted prematurely and a long term experiment with red clover had to be abandoned on account of a severe infestation with red spider. The opportunity was taken of testing spray and dipping methods for the control of the pest, in collaboration with the Insecticide Department. It was found that the adults could be satisfactorily killed, but that the eggs survived the treatment and re-infection occurred.

Investigations regarding the need of certain crops for molybdenum were, however, continued and the response of the plant to the element studied under various nutrient conditions. It was found that the quantity of calcium provided had little effect on the appearance of molybdenum deficiency symptoms, though it materially altered the size and dry weight of the crop.

B. Effect of Root Temperature and Light on Growth

For some time past experiments have been carried out in water cultures to correlate the effect of high and low root temperatures on

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growth in relation to full and subdued light intensity. The culture bottles are immersed in thermostatically controlled heated tanks, or in unheated tanks with a steady flow of cold water to keep the temperature as even as possible. Control plants are grown under normal conditions on the glasshouse bench, giving fluctuating root temperatures throughout growth. At first maximum and minimum temperature readings were made daily with a form of six's thermometers specially constructed for the purpose, but more recently two electrical recording thermometers, each fitted with four bulbs, have been installed, providing a much more complete record of what is really happening throughout the day and night.

As both the heated tanks and the thermometers are worked by electricity an experiment planned to take place under winter conditions had to be abandoned owing to the frequent electricity cuts.

Data have been obtained in connection with peas, buckwheat and flax, and are now being worked up for publication.

C. Vitality of Buried Weed Seeds

The soil samples taken from Broadbalk wheat field in 1945 for the estimation of buried weed seeds are now in their third year of examination, and are due to be completed on 30th September, 1948, after which it will be possible to compare the results with those of the 1940 sampling, and to get further evidence of the value of the 5-year fallowing cycle which is adopted on the field.

During the past year numerous enquiries have been received with regard to the control of wild oat, and an appeal was made in "Agriculture" for any methods that had been tried in various parts of the country and which offered any promise of success. The information thus received has been incorporated in a further article, and it is hoped that this pooling of scattered knowledge of this pernicious weed will extend. Meanwhile, long term pot experiments at Rothamsted on the dormancy of *Avena fatua* seeds in soil have been continued, and a similar experiment on *A. ludoviciana* has been set up. Seedlings of both species buried at depths down to 9 in. reached the surface and produced normal plants. The soil from each of the replicated pots was turned out into wooden trays about 3 in. deep and kept under suitable growth conditions. A few seeds of *A. fatua* which had been buried for 19 months at depths of 15 and 20 in. germinated under these conditions, and possibly others may appear later from the same boxes.

Bartsia odontites, a weed which is semi-parasitic on the roots of wheat in Broadbalk, has shown a very restricted period of germination in the buried weed seed experiments since 1925. Seedlings have only appeared in the sample pans from the end of February to the beginning of June, none at all occurring during the rest of the year. Experiments and observations are in hand to determine whether this behaviour is inherent in the nature of the seed, or whether it can be modified by varying conditions of germination, either in the field or glasshouse.

The experiments on the dormancy of *Urtica urens* seeds are still in progress and need to be carried on for some time yet before it can be decided whether all the buried seeds have germinated. It may prove necessary to make this a long term experiment in the absence of any outside information on the subject.

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D. Park Grass Hay

For the first time since 1919 samples were taken from all the plots on the field, instead of only from selected plots. Complete botanical separations of many of the samples are in progress, and all the rest have been subjected to partial separation into grasses, leguminous and other plants. The material accumulated since 1919 is being gradually worked out, with the intention of bringing the survey up to date since the issue of "Manuring of Grassland for Hay", which dealt with all the earlier work.

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DEPARTMENT OF CROP PHYSIOLOGY

By E. C. HUMPHRIES

Consequent upon the departure of D. J. Watson in June, for a year in Australia, his duties in connection with the Field Experiments were undertaken by H. V. Garner.

ANALYSIS OF GROWTH AND YIELD OF FIELD CROPS

Observations were made on wheat, barley, sugar beet, mangolds and potatoes during a 6-year period, including measurements of size attributes of the plant and density of the plant population (fresh weight, dry weight, plant and shoot number and leaf area per sample) at intervals during growth have been analysed and the results prepared for publication. From the estimates of Net Assimilation Rate obtained from these data, the effects of seasonal trends, year to year variation, differences between species and varieties, and the relation of Net Assimilation Rate to climatic factors were investigated (39). The variation in leaf area within and between years was also computed. Differences in Net Assimilation Rate between species and between varieties of sugar beet and potatoes were established. Variation in Net Assimilation Rate is of minor importance in determining differences in yield between years and between varieties of the same species ; these depend mainly on variation in leaf area.

An analysis was also made (40) of differences in dry matter yield of various crops produced by variation in mineral nutrition. Material from three of the Rothamsted classical field experiments, Broadbalk (wheat), Hoosfield (barley) and Barnfield (mangolds) was used. Nitrogenous fertilisers consistently increased Net Assimilation Rate. The effect of other nutrients on NAR were smaller and more variable. All treatments increased leaf area per plant but the time at which the effects occurred and the manner in which they were produced differed with different nutrients. Generally speaking the effects of varied nutrient supply were relatively greater on leaf area than on Net Assimilation Rate.

OTHER INVESTIGATIONS

The foregoing investigations indicated that leaf area is one of the most important factors influencing dry matter yield and it is of importance to determine the factors that affect it. A. G. Morton investigated certain aspects of this problem and found that of the factors investigated nitrogen was the most important in determining rate of leaf production by the apical meristem of sugar beet.

The considerable amount of data relating to the potato storage experiments outlined in the report for the war years has been analysed, and the first part prepared for publication (42).

E. C. Humphries was appointed in February, 1947, to investigate root problems. The object is to see how soil treatments such as different methods of cultivation or of fertiliser application affect the activity of roots so as to produce differences in crop yield. Preliminary results have been obtained on the nutrient uptake of excised roots from plants grown under controlled conditions of nutrient supply in water culture and it is hoped to extend the method to field material.

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DEPARTMENT OF STATISTICS

By F. YATES

The demand for statisticians trained and experienced in agricultural and biological work, mentioned in the 1946 Report, has continued to affect the Department. Following the loss of Mr. Kempthorne, on his appointment to an Associate Professorship in the Statistical Laboratory, Ames, Iowa, at the end of 1946, Mr. Quenouille was appointed to a Lectureship in Statistics at Aberdeen University on completion of his year's study leave at Cambridge, and Mr. Anscombe has been appointed to a Lectureship in Statistics in Cambridge University in succession to Dr. M. S. Bartlett, who was appointed to the newly created Chair of Statistics at Manchester University. Mr. Anscombe left to take up his appointment in January, 1948. In addition to these University appointments, Mrs. Mathison has been appointed Statistician to the East Africa Groundnut Scheme. Fortunately the increased recognition of statistics in the Universities is already beginning to bear fruit, and it may be confidently expected that the number of able mathematicians who become interested in biological and agricultural research statistics in the course of their university careers will increase considerably in the future.

In order to encourage more recruits to agricultural statistics, the Ministry of Agriculture and Fisheries and the Department of Agriculture for Scotland have instituted post graduate Scholarships in Agricultural Statistics, and three of these were awarded to scholars for study and training at Rothamsted during the year 1947–48.

AGRICULTURAL RESEARCH STATISTICAL SERVICE

Final arrangements for the setting up of a general Agricultural Research Statistical Service were completed during the year, and the following announcement was circulated by the Ministry of Agriculture and Fisheries to Research Institutions and the National Agricultural Advisory Service in December, 1947:

> On the basis of proposals made by the Agricultural Research Council and the Agricultural Improvement Council, it has been agreed between Rothamsted Experimental Station and the Ministry that the Statistical Department at Rothamsted should be expanded into a general Research Statistical Service.
>
> The Department has had long experience in dealing with statistical problems arising in design and analysis of experiments, the planning of field experiment programmes (so as to ensure the best utilisation of experimental resources), the planning and analysis of scientific surveys, and the critical analysis of large bodies of experimental material, and the new Service will in the main specialise in these classes of problem, though it will be prepared to assist in other work in so far as resources permit.
>
> It is intended that the Research Statistical Service shall give assistance to agricultural research stations, the National Agricultural Advisory Service and similar bodies in handling statistical problems beyond their resources. It is expected that

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the Service will be of value both to Institutions which have their own statistical staff and to Institutions and workers who have not at present any proper statistical facilities.

It is not intended that this expansion should preclude the appointment of staff with statistical knowledge in Research Institutions where the nature and volume of the work appear to justify such a course. At the moment, however, the supply of trained and experienced statisticians is inadequate and it is hoped that the Research Statistical Service will be able to bridge the gap that at present exists as well as providing a source of trained statisticians for the future.

The use of Hollerith punched card equipment is planned to assist in the analysis of data from large-scale surveys, and to facilitate research into improved methods of analysis of material of this type.

Institutes or individuals wishing to make use of the Research Statistical Service should communicate direct with the Head of the Statistical Department, Dr. F. Yates, at Rothamsted Experimental Station, Harpenden, Herts.

It is not intended that any charges shall be made for the use of the Service by Agricultural Research Institutes or the N.A.A.S.

The setting up of this Service has already resulted in an expansion in the work of the Department. In particular the Provincial Experiments Committees of the N.A.A.S. are consulting us freely on problems arising in the design of their experiments, and Dr. Boyd has been actively engaged in making personal contact with the various Provincial Centres. The Department has also done a good deal of work for a number of research centres.

The Department has been extensively consulted by research workers from the colonies on the design of field experiments, particularly long-term experiments of fertility in tropical Africa. In this work Dr. Yates and Dr. Crowther actively collaborated.

United Nations Sub-Commission on Statistical Sampling

Dr. Yates was invited by the Foreign Office to become a member of the United Nations Sub-Commission on Statistical Sampling, which held its first session at Lake Success in September, 1947. The other members of the Commission are: Professor G. Darmois (France), Dr. W. E. Deming (U.S.A.), Professor R. A. Fisher (U.K.), Professor P. C. Mahalanobis (India). This Sub-Commission was set up largely at the request of the Food and Agriculture Organisation, with a view to the introduction of sound sampling methods in the World Census of Agriculture which is planned for 1950. The work of the Sub-Commission is also of importance in connection with the World Census of Population planned for the same year. The Sub-Commission has drawn up a report on the use of sampling with particular reference to these Censuses, which has already had considerable influence with those concerned with the planning of the Censuses. The Food and Agriculture Organisation held a conference of representatives of various countries concerned in the administration of under-developed areas in London in December, 1947, with the object of discussing the procedure of the Agricultural Census of such countries. Dr. Yates attended this conference as the representative of the United Nations.

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One of the recommendations of the Sub-Commission was that a manual should be prepared, as a matter of urgency, giving instructions on the use of sampling methods in censuses and surveys, with particular reference to the projected Agricultural Census. Dr. Yates undertook to prepare a draft of this manual, and considerable progress has already been made.

In the course of his visit to the United States, Dr. Yates attended the International Statistical Conference in Washington, D.C., where he contributed a paper to the Session on the Theory of Statistical Sampling (59). He also paid visits to the Statistical Laboratory at Ames, Iowa, the Institute of Statistics at Raleigh, North Carolina, the Connecticut Agricultural Experimental Station, New Haven, and various other institutes. Two outstanding impressions gained on these visits were the wide adoption of the modern methods of experimental design developed at Rothamsted, particularly the use of lattice designs in variety trials and plant breeding work, and the great developments that have occurred in the use of sampling methods both in agricultural and other surveys.

Research in statistical methodology

Mr. Anscombe continued his work on the sampling theory of negative binomial and logarithmic distributions, which is required in the study of insect populations, etc. Two papers on this subject have been prepared for publication (43), (44).

Dr. Yates completed his investigation of problems arising in systematic sampling, that is, the taking of sampling points evenly spaced along a line, or over an area, instead of randomly located sampling points (56). This work involved a good deal of heavy computation in which a number of members of the Department gave considerable assistance. Mr. Quenouille also carried out an investigation in this field (51).

While at Cambridge, Mr. Quenouille made a study of the analysis of time series, such as arise in meteorology, agriculture and economics. He has prepared a number of papers on this subject (46), (47), (48), (49), (50). A paper on an earlier investigation arising out of a problem in bomb distribution, which he undertook shortly after he came to Rothamsted, is being published (52). He also contributed a mathematical appendix to a paper by P. C. T. Jones and J. E. Mollison on the estimation of soil bacteria (53).

Dr. Yates investigated the methods of analysis appropriate to data derived from genetical experiments involving all possible reciprocal crosses of a number of parental strains (54), and also methods of analysing two-way contingency tables in which one or both the classifications refer to characters, such as grades, having an underlying quantitative basis (55).

The problem of the estimation of the sampling errors of the mean of a number of sample determinations in stratified sampling when certain sampling units are missing has been investigated by Mr. Healy, and a note on the subject is being prepared. This problem arises in sampling for mean egg weight by trap nesting on particular days, since hens do not lay eggs on all days. Mr. Read has prepared a note on the practical aspects of this problem.

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Design of experiments

No papers have been published in this field other than those which have already been prepared at the end of 1946, but various problems in experimental design have been under investigation, particularly in connection with long-term experiments and animal nutrition experiments. It is hoped that papers on these subjects will be prepared in the course of the coming year.

In addition, the need for a new text book on experimental design is becoming increasingly apparent. Descriptions of many of the more modern methods, which are now in current use, are only available in papers published in scientific journals, and reprints of many of these papers are now no longer available. It is intended to begin work on this text book as soon as the sampling manual is completed.

Sampling surveys

During 1947 field work for the Survey of Fertiliser Practice was continued in the South-Eastern Province, and was completed in the South-Western and Welsh Provinces. Duplicated reports have been issued for the following counties: South Essex, Isle of Ely, Lincolnshire (Holland), Lincolnshire (Lindsey), Warwickshire, Yorkshire (West Riding). Reports are in preparation for three counties of the Northern Province, and the analysis of the survey data for a further six counties was completed.

Arrangements have now been made by the Ministry for the publication of all the reports of this survey and revised copies of a number of reports have already been transmitted to the Stationery Office. It is hoped that in future the issue of duplicated reports will be unnecessary, their place being taken by the immediate publication of the final report.

The data provided by the Survey on the extent of combine drilling of cereals and other crops in different parts of the country were summarized and a report has been published in *Agriculture* (58).

A survey of the conditions under which milk is produced on farms was planned for 1947 by the Field Experiments Committee of the Agricultural Improvement Council, but it proved impossible to undertake any field work. It is intended, however, that a pilot survey shall be undertaken in 1948. The planning and analysis of the results of this survey will be the responsibility of this Department.

Assessment of yields of grazed pastures by grass cutting techniques

The work begun in 1945 in collaboration with the Chemistry Department and the Grassland Improvement Station on the evaluation of the yield of pastures by grazing and grass cutting was continued in 1947, samples being taken throughout the season on the Highfield grazing experiment. Statistical analyses of these experiments and of others carried out in other Provinces are being carried out by Dr. Boyd. It is intended that a report of the work shall be published shortly.

Resazurin research scheme

Work on this scheme has continued during the year under the supervision of Mr. Eddison. The analysis and report of an

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experiment dealing with temperature compensation for storage prior to test was completed. The preliminary analysis of an experiment designed to determine the variability of milks from day to day and from churn to churn was also completed. A field trial of the methods evolved in the previous work has been instituted.

Entomology and Parasitology

In addition to work for the various departments of Rothamsted, Mr. Anscombe has acted as statistical advisor to the Advisory Entomologists. The scheme of observations of certain important pest insects ("Calendar insects") has been running smoothly. Some special observations were made last winter, 1946-47, to find out how many soil borings need be taken per field to obtain a reliable estimate of potato eelworm cyst infestation. Further observations, which should give all necessary information, are being taken this winter (1947-48).

An experiment carried out by the Parasitology Department, St. Albans, in 1946 on the use of D.D. against potato root eelworm was analysed, and six similar experiments carried out in 1947 are now in course of analysis.

A small co-operative experiment to see if different laboratories could get similar results in the determination of pyrethrin content of samples of pyrethrum flowers was examined and reported on. A much larger international experiment has been discussed.

National Institute for Research in Dairying

Mr. Healy has acted as statistical advisor to the National Institute for Research in Dairying. A thorough analysis of certain change-over nutrition experiments on dairy cows was carried out and points in the theory of the design and analysis of these experiments have been elucidated. Other items of work have included interpretation of milk flow curves, the development of tactile tests in rheology (which has application to cheese making) and hormonal treatment of goats.

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DEPARTMENT OF PLANT PATHOLOGY

By F. C. Bawden

Viruses and virus diseases

The main lines of work described in previous reports were all continued. In the laboratory particular attention was paid to the conditions that affect the extraction of potato virus X from plants and that cause it to aggregate and inactivate (69 and 70). Extracts of *Phytolacca* species have long been known to inhibit plant viruses; the inhibitor was isolated and identified as a glycoprotein (82).

Electron microscopy showed that particles of potato virus X vary in size in a similar manner to those of tobacco mosaic virus. Some thousands of particles of tobacco mosaic virus from preparations made in different ways were measured to see whether any basic particles could be identified. Using micro-dissection methods, specimens suitable for examination in the electron microscope were made from cell contents of infected plants. These preparations showed the presence of large numbers of virus particles in X-bodies and crystalline inclusions caused by tobacco mosaic virus. The cytoplasmic inclusions produced by severe etch virus were found to contain large numbers of sub-microscopic crystals of various forms.

The effects of fertilisers and environmental conditions on the susceptibility of plants to virus infection were studied in the glasshouse. The susceptibility of bean and tobacco plants to tobacco necrosis, and of *Nicotiana glutinosa* to tobacco mosaic and tomato bushy stunt viruses, was consistently increased by placing plants in the dark before they were inoculated. Short periods in the dark produced responses similar to those found for prolonged periods of shading. Twenty-four hours in the dark usually produced the maximum response with beans, but with tobacco plants periods of up to 5 days increased susceptibility. Placing in the dark after inoculation had relatively little effect, but most often decreased susceptibility. It seems that infection occurs in two stages, the first of which is hindered by the presence of large amounts of photosynthetic products.

Interpreting the effects of fertilisers on susceptibility to viruses is complicated because of the effects of nutrition on the size of the plants. Assessing susceptibility by numbers of lesions per leaf may give different results than if numbers per unit area are considered. Also, when assessing susceptibility on the basis of virus concentration, there may be large differences depending on whether amount of virus per plant or per given volume of extract is considered. Phosphorus is much more important than nitrogen or potash in increasing susceptibility of plants to infection with tobacco mosaic virus and in increasing virus multiplication, but it is also the most effective nutrient in increasing plant size. Assessing susceptibility by numbers of lesions per leaf, phosphorus increased susceptibility

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by about 5 times, but assessing it by lesions per unit area, phosphorus increased susceptibility by less than 50 per cent. Phosphorus doubled the concentration of virus in sap and increased the total virus content of plants by 10 times. In the presence of phosphorus, but not in its absence, nitrogen also increased the concentration of virus in sap and the total content of infected plants. Virus isolated from the differently treated plants did not differ in infectivity.

Fertilisers had no effect on the susceptibility of tobacco plants to potato virus Y when plants were colonised with single infective aphides.

Strains of cucumber mosaic virus obtained from different naturally-infected hosts differed, not only in host range and symptoms produced, but also in the ease with which they are transmitted by aphides, and the concentration they reach in plants. The last probably accounts for the differences found in such properties as dilution end point and thermal inactivation point. *Phaseolus vulgaris* var. Bountiful was found to be a suitable host for local lesion work with cucumber mosaic virus. During the winter it produces discrete necrotic local lesions, but during the summer it appears to be immune.

Studies on the insect relationships of pea mosaic and pea enation mosaic viruses showed the first to be a non-persistent and the second a persistent virus. A virus found causing severe damage to broad bean in the field seems to be different from any previously described in that it was transmitted by inoculation but not by aphides.

Field work on the epidemiology of sugar beet diseases was continued. The relationship between the aphis infestations of crops, trap catches of winged aphides and the prevalence of virus yellows was studied in the main beet-growing districts of eastern England. In a detailed survey of a limited area of Lincolnshire, infection varied in individual crops from 5 to 100 per cent. Rate of infection could not be correlated with any known over-wintering sources of virus or aphides, but it was increased by late sowing and thin stands of plant. The effect on the incidence of virus yellows in sugar beet stecklings sown at different dates and in different districts was studied. Healthy seed crops were produced by raising stecklings in districts removed from other sugar beet, but as a practical measure it raises difficult problems in transporting stecklings to the seed grower at planting time. To avoid these difficulties, experiments on clamping stecklings have been started. Tests of various strains of sugar beet and lines selected by the Plant Breeding Institute, Cambridge, were made in the field for any tolerance to yellows.

The comparative effects of yellows and mosaic in reducing the yield of sugar beet and mangolds infected at different dates were tested in a field experiment.

The usual field surveys and experiments on potato virus diseases and their insect vectors were made. The results are described in the review of work on potato virus diseases done in the department since 1940, which in part summarises the Research Bulletin prepared by Doncaster and Gregory (68).

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Mycology

Work was continued on the violet root rot disease caused by *Helicobasidium purpureum* Pat. After completing a study of the production and growth of mycelial strands, attention was turned to the conditions influencing the survival of the fungus in the soil. The survival of colonies of *H. purpureum* on nutrient agars of different composition, buried in the soil, was first investigated. Plates of different nutrient agars were inoculated with *H. purpureum* and incubated for 2 months at 25°C.; the fungus colonies were buried in soil for 3–4 months, and then tested for viability by inoculation to carrot seedlings. Survival was prolonged by raising the carbohydrate concentration of the medium, but shortened by excess of nitrogen. The optimum nitrogen requirement for survival increased with rise in carbohydrate content of the medium. Survival of colonies was correlated with the production of firm resilient sclerotia around the centre of the colony. The depressing effect of excess nitrogen upon production of sclerotia and survival of colonies is attributed to an increased density of mycelial growth, leading to reduction of carbohydrate level below that required for maturation of viable sclerotia. The effect of various farming practices on the incidence of violet root rot on sugar beet crops was also studied.

Experiments have been carried out on survival in soil of the resting spores of *Plasmodiophora brassicae* Woron., the cause of clubroot. Under soil conditions favourable to infection, resting spores obviously germinate spontaneously in fallow soil, for tests show that the spore population falls by about 90 per cent. during the first few weeks after a spore suspension has been added to the soil. Thereafter, decline in viable spore population is slower. The spore population falls less rapidly in dry soils and alkaline soils than in wet or acid ones; thus soils unfavourable for infection seem also unfavourable for spontaneous spore germination. Some indication was obtained that many spores germinate soon after an alkaline soil is acidified. Trials have been carried out with substances likely to promote spore germination in fallow soil, such as allyl isothiocyanate, benzaldehyde, and picric acid. The life-cycle of the parasite is still imperfectly understood, and to gain more information attempts were made to prepare bacteriologically sterile spore suspensions with which to inoculate sterile plants and establish the organism in pure culture.

There was less eyespot (*Cercosporella herpotrichoides* Fron.) at Rothamsted in 1947 than at any time since research was first made in 1937. The late spring and dry summer both limited infection, and the results of field experiments contrasted strikingly with those obtained in 1946. In 1946 eyespot was prevalent on the experiment on Little Knott, straw was long and there was much lodging, but there were few weeds. Straw and grain yields were 67·4 and 27·0 cwt./acre. Spraying with sulphuric acid reduced eyespot, reduced lodging and increased yield by 1·8 cwt./acre. Increasing seed rate from $1\frac{1}{2}$ to $3\frac{1}{2}$ bushels/acre and of ammonium sulphate from 0 to 4 cwt./acre increased lodging, but had little effect on yield. In 1947 the eyespot was little, straw was short and there was no lodging, but there were many weeds. Straw and grain yield were 36·7 and 26·0 cwt./acre. Spraying reduced weeds greatly and increased

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yield by 1·6 cwt./acre. Increasing rate of sowing from 1 to 3 bushels/acre gave increased yields only when nitrogen was applied.

From the results of experiments and surveys made during the last 10 years the effects on the incidence of eyespot of increasing the frequency of wheat and barley in the rotation were assessed quantitatively. Next to rotation spring rainfall was the most important determinant, though any factors that increase humidity within the crop favour eyespot and lodging.

Experiments were made to assess the effect of downy mildew (*Peronospora Schachtii* Fuckel.) on yield of sugar beet and to test the effects of planting date, isolation from other beets and sprays in controlling infection of stecklings.

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DEPARTMENT OF BIOCHEMISTRY

By N. W. PIRIE

The main work of the Department continues to be an investigation of the composition of the normal and virus infected leaf; we are not primarily concerned with the elementary composition, though this has been investigated during the year, but with the disposition of the various enzymic and structural components of the leaf and their relationship to each other and to the virus that may be present. In work of this type it is always necessary to consider the extent to which the conclusions may be invalidated by changes taking place during the mincing and extraction of the leaves. We have already described the artefacts that can be produced by fine milling, and the demethylation of the leaf pectin by its own pectase. Many leaves, especially those of the Cucurbitaceae, give alkaline extracts when the fibre residue left after expressing the sap is extracted with water. This phenomenon has been studied by M. Holden and she finds that it is due to an apparently non-enzymic reaction between pectic acid, calcium carbonate and phosphate. An understanding of the mechanism will enable us to avoid the inactivation of viruses or enzymes which would result if uncontrolled pH drifts were taking place. Although most plant viruses are not destroyed by proteases the complexes that they form with various leaf components are destroyed. M. V. Tracey has estimated the protease content of a variety of leaves and leaf extracts and finds that the activity present in the leaves normally used in virus work is small. There is no reason to think that this trace of protease has any serious effect on any of the conclusions that we have so far drawn.

The effects of fertiliser treatment and illumination on the susceptibility of plants to infection and on the multiplication of viruses in the infected leaf have been established, mainly by work in the Plant Pathology Department. Holden and Tracey have measured the effects of fertiliser treatments on the composition of tobacco plants grown under the conditions used in virus work. Supplements of nitrogen and phosphorus increased the dry matter, N and P contents of the plants. Nitrogen alone decreased the protease and increased the pectase content whereas phosphorus alone had the opposite effect. The effect of fertilisers on the composition and virus content of tobacco leaves systemically infected with tobacco mosaic virus was studied in a similar way. Under conditions of high phosphorus but without increased nitrogen, virus accounted for four-fifths of the nitrogen associated with the fibre.

In earlier work on the liberation of viruses from leaves some observations were made on the liberation of protein from the leaf residue and the conditions under which fairly complete mechanical liberation was possible were laid down. This work has now been extended by Crook and Holden to some thirty plant species. Wide variations were found in the extractability of the nitrogen in different species. These figures, which will be extended, are both of theoretical interest and of practical value for an investigation of the technical separation of leaf protein which is about to be made.

During the past few years our knowledge of the manner in which viruses are bound in the infected cell has been increased by

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work on plant viruses in Rothamsted and on animal viruses in some other laboratories. Material with properties similar to those of highly purified virus preparations probably exists in the cell but it is accompanied by variable amounts of material that can be converted into purified virus but that is originally in a chemically more complex state. This phenomenon is still being studied with tobacco mosaic virus, tomato bushy stunt, and the Rothamsted strain of tobacco necrosis virus but no unequivocal evidence whether the complex is the primary or secondary form has been found Variable, but often large, amounts of virus are attached to the leaf fibre as well. This is not set free by grinding unless grinding of such an intensity that there is a probability of it bringing about chemical changes is used. The enzymes present in the crop of the snail readily bring about the liberation. An attempt is now being made to find which particular enzyme in this mixture is responsible.

The leaf contains a wide range of structural materials, protein, pectin, cellulose, and the more vaguely defined materials lignin and hemicellulose. The first two are probably not concerned in the anchoring of the bound virus. Lignin also is probably not involved because virus is liberated by enzyme mixtures that are not known to affect it. The roles of cellulose and the hemicelluloses could be disentangled if specific enzymes were available but in the absence of these, evidence can be got from simultaneous estimations of pentose, glucose, galactose and uronic acid. The estimation of these substances in the presence of one another is a matter of some difficulty. Tracey has developed a quick and convenient micro-method from the conventional uronic acid method and has made a more thorough study than had been made before of its specificity. He has also shown that it can be used for the determination of soil uronic acid.

The snail enzyme, although powerful, has defects. It is only readily available in summer and it has not proved possible to purify it; large amounts of nitrogen and carbohydrate have to be added, in the form of snail slimes, to any digest in which its action is being studied. We are investigating various fungus enzymes and get encouraging results with Botrytis and Aspergillus. Some fungus extracts contain predominantly polygalacturonase and our work has been greatly facilitated by a gift of highly purified polygalacturonase from Dr. Lineweaver in California.

Many factors influence the rate of action of these enzymes and we are studying the effects of different pretreatments of the leaf. In this we are, of course, limited by the fact that the ultimate object is knowledge of the manner in which virus is attached to the leaf so that no treatment is useful if it would destroy the virus. Removal of calcium ions from the leaf is a valuable step and so is the simultaneous dehydration and de-fatting that extraction with alcohol-ether mixtures brings about. This has the additional advantage that it gives the leaf a brittle texture that makes grinding very easy.

Although an investigation of the nature of soil organic matter and of the composition of some of the bacteria and funguses that play a part in building up this organic matter is part of the programme of the department, work on this aspect of the biochemistry of soil has not yet begun. Mann, in collaboration with the

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Chemistry Department, has investigated the metal-organic-matter complexes of the soil. This work was prompted by the observation that the manganese in pyrophosphate extracts of organic soils was in the divalent form whereas earlier work with similar extracts from mineral soils had shown that the manganese was in the trivalent form. It proved impossible to decide what proportion of the divalent manganese arose from organic complexes because the pyrophosphate extracts reduced manganese in higher states of oxidation. However, neutral and alkaline organic soils retain added divalent manganese in a form not recoverable by repeated extraction with M ammonium acetate. In some cases the recovery was increased by the addition of low concentrations of Cu, Cd, Ni, or Zn salts to the ammonium acetate. These mixtures also give higher figures for the exchangeable manganese in untreated soil than extraction with ammonium acetate alone. The effect is particularly marked with copper, which appears to catalyse the reduction of the more highly oxidised manganese of the soil. The retention of added manganese is correlated in a general way with the organic matter content of the soil and all these results support the view that the manganese is associated with the soil organic matter.

In attempting to extract metal-organic complexes, three main fractions have been obtained: the first is water soluble after extraction of the soil with sodium chloride, the second is soluble in pyrophosphate, and the third in 2 per cent. sodium hydroxide. Manganese or copper, added as sulphate, during the sodium chloride extraction, was recovered in the subsequent water or pyrophosphate extracts. In the water extracts the metals were still combined with the organic matter.

The results appear to be of agricultural significance since manganese deficiency occurs typically on alkaline organic soils and copper deficiency has frequently been attributed to fixation of copper by the soil organic matter.

Lees has got more evidence for the view already put forward that copper is essential for nitrification. In soils treated with poisons for copper (such as diethyldithiocarbamate) nitrification is inhibited but activity can be largely restored by small amounts of copper sulphate. Higher concentrations of copper and low concentrations of zinc inhibit strongly; these inhibitions depend on the pH and organic matter content of the soil. Lees suggests that at neutral or alkaline pHs metal-organic complexes are formed in which the metal is not readily available to the nitrifying bacteria.

In collaboration with the Microbiology Department Lees has investigated the trace element requirements of cultures of nitrifying bacteria from Rothamsted soil. An outstanding effect is the stimulating effect of iron. Mixtures of copper and iron have no more effect than iron alone, but either removes the inhibitory effect of an unbalanced mixture of other trace elements. A proper balance of elements is more important than the absolute level of any one ion. The effect of many organic substances on nitrification in soil has been tested but none of them have had any pronounced effect under the conditions employed.

During the early part of 1947 N. W. Pirie was absent in U.S.A. and Canada, and he attended the International Cytological Congress in Stockholm in July.

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DEPARTMENT OF ENTOMOLOGY

By C. B. WILLIAMS

INVESTIGATIONS

Dr. Williams has continued his studies of insect migration, insect populations, and of the effect of weather conditions on the activity and abundance of insects.

The work on migration has consisted chiefly in the collection of a large number of records of the occurrence of immigrant insects into England during the last few years; and particularly of the Cabbage-White Butterfly and the Silver-Y Moth, both of which have come in from abroad in very large numbers recently and have done extensive damage. Co-operation has been established with workers on the Continent and a very much wider knowledge is now obtainable of the distribution of these migrants in Europe in different years. Some evidence of mass movement was obtained for the Antler Moth, a serious pest of upland pastures, which we have suspected for many years as a possible migrant.

In the study of the structure of insect populations progress has been made in the application of statistical methods to the relative abundance of different species of insects in a mixed population, which gives a new conception of the "balance" in such conditions. Also a study has been made of the importance of competition in preventing the development of two closely related species in a single ecological community. In a paper (128) evidence is brought forward that the advantages of close relationship (e.g., species in the same genus) may outweigh the disadvantages of competition, so that small communities contain fewer genera than would be expected in a community of the same size in which the species were selected without reference to generic relationships.

Before the war considerable work was carried out on the effect of weather conditions on the activity and abundance of insects by means of regular captures in a light trap; this work was a wide study on the effect on "insects" as a whole. In the last two years the study has been resumed, with the assistance of Mr. Banerjee, to test the possibility of working with single species of insects. About twenty abundant species of Lepidoptera have been chosen for study and the results are promising. The main difficulties have been: (1) the relatively short period over which any single species appears, (2) the rapid natural rise and fall of numbers during the brood, and (3) the relatively small numbers of any one species obtained in a trap. To overcome this last difficulty the number of traps has been increased to three, but it would be better still if this could be again increased to six.

The opportunity was taken of the Presidential Address to the Association of Applied Biologists (127), to show how the past activities of the Entomological Department fit into a general scheme of research in Applied Insect Ecology; with its object the study of the causes of insect outbreaks and their prevention, rather than continual expenditure on direct control methods.

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The scheme is as follows:—

FACTORS AFFECTING THE TOTAL POPULATION

The Physical Environment

*Geology and Geography

*Weather and climate

The Biological Environment

Food supply

*Parasites and Predators

*Competition

FACTORS AFFECTING THE DISTRIBUTION OF THE POPULATION

*Migration, or deliberate movement

*Drift, or accidental movement by natural causes

Accidental distribution by human agency.

Work in those sections marked * is already being carried out, and it is hoped that the scope might be extended to the other fields.

Dr. Barnes reports that owing to the part-time availability of an untrained assistant he was able to extend both the wheat blossom midges study as well as the slug investigations. He also states that his attendance at the Conference of Advisory Entomologists' meeting at Aberdeen during September was of immediate and direct use in establishing contacts and interchange of views concerning gall midge and slug problems in the field.

The progress of Dr. Barnes' investigations is as follows:—

1. The long-term study of the incidence of the wheat blossom midges on Broadbalk was successfully carried out for the twenty-first year in succession. While the numbers of *Contarinia tritici* remained high (21,094 per 500 ears compared with 29,638 in 1946) those of *Sitodiplosis mosellana* fell very considerably (599 per 500 ears compared with 3,853 in 1946). This drop is probably local and not general throughout the country. The percentage grain infestation on Broadbalk remained at 13 in the case of *C. tritici* but for *S. mosellana* it fell from 13 to 2. Since *S. mosellana* does more damage than *C. tritici* this drop is important. One may expect both species to decrease generally for the next year or two.

In 1947 the wheat blossom midges apparently responded to the abnormally hot weather at the end of May and early in June more than the wheat did. The result was that *Contarinia tritici* started emerging before the wheat plant was available for oviposition. This was observed both on Broadbalk and on a farm at Bedford. Consequently these early midges laid their eggs on a weed, Couch grass, both on Broadbalk and at Bedford.

The emergence of the midges on Broadbalk field was again studied and checked against that in the new insectary at Rothamsted Lodge. The correspondence was surprisingly high.

The study of the longevity of viable larvae in the soil showed that some *S. mosellana* gathered in July, 1939, emerged successfully during 1947; they had thus survived 8 winters in the soil. It is of more than passing interest to note that this survival in the soil has now been partly confirmed by Mr. Cohen, Advisory Entomologist in the Northern Province, and his colleagues who have found large numbers of living *S. mosellana* larvae in fields which have not been under wheat since 1945 and 1944 respectively.

2. As a direct result of the observations on the wild host plants of the wheat blossom midges, a *Stenodiplosis* gall midge was recorded

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for the first time from Couch grass both at Bedford and Harpenden. Superficial examination leads one to suppose this species of midge has come from Foxtail grass. This possible change of host plant may be of importance and it has already aroused the interest of Mr. W. Cottier, Senior Entomologist, of the Plant Disease Division in New Zealand.

3. Short biological studies were made on other gall midges including *Wachtliella ericina* on ornamental Heather, *Wachtliella rosarum* and *Macrolabis luceti* on Rose, *Contarinia solani* on Woody Nightshade (in an attempt to see whether this species would live on Deadly Nightshade or Tomato) and *Therodiplosis persicae* which lives on red spider on Peach and other plants grown under glass, e.g., Raspberry at Dundee.

4. The slug investigation was largely a comparison of slug activity at Bedford compared with that in Harpenden.

5. The appearance of further volumes of "*Gall Midges of Economic Importance*" was again delayed. But the final proofing and indexing of Vols. 3 and 4 was completed in August. Publication has been held up owing to shortages of binding cloth and paper, but now publication of Vol. 3 is promised for 24th March, 1948, but there is still (January, 1948) no news of Vol. 4.

Owing to this delay Dr. Barnes shelved the completion of further volumes, but intended to complete two further volumes in the year ending 30th September, 1948.

6. Identification of gall midges sent in has been almost entirely restricted to those sent in by Advisory Entomologists and others in this country. Time, however, will soon have to be made to deal with overseas consignments which have been accumulating.

Dr. Evans reports as follows on his work with Dr. Guild on the relations between earthworms and soil fertility.

The studies on the life-cycles of the common species have been continued.

FIELD STUDIES

Annual fluctuations, the results of the three years' work, suggest that, in permanent pasture, large scale fluctuations do not occur.

In leys, after arable, there is a rapid build up of the population.

In arable, after permanent grass, there is but little decrease in population during the first year but a rapid diminution thereafter

SOIL STRUCTURE

The weight of wormcasts produced per acre per annum on pastures of varying age varied from 1–25 tons and it was calculated that from 4–36 tons of soil pass through the alimentary tracts of the total population present. The percentage pore space of a soil containing a high population of casting species is much greater than that of one containing a high population of non-casting species, i.e., 67 per cent. as against 40 per cent. The amount of coarse sand relative to silt and clay increases appreciably with depth in two old pastures and this distribution is probably the result of the long continued activity of earthworms.

EFFECTS ON SOIL FERTILITY

A large scale pot experiment showed that the presence of earthworms in numbers approximating to those found in the field gave a significant increase in yield of the test crop, mustard. As a

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result of the four large scale pot experiments carried out during these investigations we have reached the conclusion that this method is not suitable and that, if the investigations are to be continued, experiments should be carried out in cylinders, at least 3 ft. in diameter, sunk into the soil and exposed to natural weather conditions. The tentative conclusion that we have reached is that earthworms are not of any great importance under arable conditions but that they are of great importance in soil uncultivated by man, i.e., permanent pasture, heaths and broad-leaved forests.

Dr. Johnson reports as follows in connection with his work on the distribution of aphididae in relation to weather conditions and field outbreaks.

A. Sampling Aphids on the bean crop

A sampling technique has been developed which enables the number of aphids, predators and parasites on the bean crop to be estimated on a satisfactory statistical basis. The method depends on selecting sample plants at random, removing all aphids from them and estimating the numbers by cliquot samples from a suspension in water. A rapid assessment of numbers, growth of populations, changes in proportions of instars, alatae, etc., can now be made and provides for the first time, with this insect on beans, a basis on which to compare infestations between plots or to study quantitatively the growth and decline of the populations themsilver. The results of last year's work are now being analysed.

B. Local Flighting

Hitherto local flighting has been studied mainly by means of nets or sticky traps which have the disadvantage of sampling relatively more insects as the wind-speed increases. Since the number of aphids in the air is itself dependent on wind-speed the use of these traps introduces an undesirable complication.

Experiments have, therefore, been made with two types of suction trap, which, by sucking a known and constant quantity of air through a vertical duct, gathers insects from known volumes of air.

Continuous records of aphids in these traps have been made throughout June-December, 1947, in two localities—one in an open field and one over a small bean patch. Identification of the aphids and analysis of their numbers in relation to times of day and weather and degree of infestation of the crop are now in progress.

C. Trapping of higher altitudes

Throughout the season trapping has been in progress at the R.D.E., Cardington, where nets have been flown almost daily from a barrage balloon cable at the following heights: 50, 250, 500, 1,000, 1,500, 2,000, 3,000, and 4,000 ft. The material gathered in these nets amounts to several thousands of aphids, which are now being identified. A quantitative analysis of numbers of aphids in relation to meteorological conditions is in progress.

D. Collection of Black Aphis for Biometrical Study

A collection of Bean Aphis from beans in different localities all over the country and black aphids from other hosts at Kew and near Rothamsted have been made. The intention was to study the limits of morphological variation of the bean aphid and its relations and to see if local differences occurred. A start has been made on the measurement of some characters but pressure of other work has put it in abeyance.

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BEE DEPARTMENT

By C. G. Butler

On 1st October, 1946, the advisory work and disease diagnosis, including the examination of sample brood combs submitted under the Foul Brood Disease of Bees Order, that has in the past been carried out by members of the Bee Research Department, was taken over by the National Agricultural Advisory Service of the Ministry of Agriculture and Fisheries. This advisory work is now being continued and extended by the N.A.A.S. bee-keeping officers under the supervision of Mr. P. S. Milne, who had previously been looking after this part of the Bee Department's work. This bee-keeping unit of the N.A.A.S. is at present sited at Rothamsted alongside the Bee Department the members of which, having been released from advisory work, are now able to devote all their energies to research.

This, then, is the first report of the Bee Department in recent years in which no mention is made of advisory work carried out by members of the Department. The resignation of Mr. Milne from the Rothamsted staff and the transference of the advisory work to the N.A.A.S., together with the removal of the Bee Department to Rothamsted Lodge, have necessitated a thorough reorganisation. As a result it has been possible, almost for the first time, to plan a number of long term researches in the knowledge that the advent of an unexpected amount of advisory work will not in future be likely to upset the programme and necessitate abandonment of work that has been commenced.

Pollen collecting behaviour of honeybees

During the summer of 1947 C. R. Ribbands made observations on the behaviour of honeybees when collecting pollen and, to a lesser extent, nectar, in a specially planted garden of Shirley Poppies, Eschscholtzias and Nasturtiums, from all three of which the bees collected pollen only, and Limnanthes and Nemophila, which yielded both nectar and pollen. The bees were anaesthetised and marked in such a way that individuals could readily be recognised and their movements recorded from day to day.

It was concluded that foraging honeybees exhibit a pattern of trial and error learning of considerable complexity. They compare the ease of obtaining a load from the flowers which they happen to be working with their memory of the ease with which they have obtained loads from the same and other sources in the past, and continually choose the best of those alternative crops with which they become acquainted.

A paper describing this work in full has been prepared for publication (135).

The effect of anaesthetics upon foraging behaviour

In an investigation of methods of anaesthetising and marking bees C. R. Ribbands has found that chloroform is a very satisfactory anaesthetic for bees and does not affect either their memory or behaviour. However, pollen collecting bees that are anaesthetised with either carbon dioxide or nitrogen usually cease to collect pollen and harvest only nectar. If bees that have been collecting from a plant which yields both nectar and pollen are anaesthetised with

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carbon dioxide or nitrogen they frequently return on recovery to the same plant, but henceforth collect nectar only from it. It is hoped to study the effects of these anaesthetics in detail during 1948. The results that have so far been obtained suggest that carbon dioxide produces a physiological change in the bee (possibly as suggested by V. B. Wigglesworth by reducing the rate of oxidation of acid metabolites) which is equivalent to ageing. This hypothesis is compatible with O. Mackensen's discovery that if virgin or inseminated queen bees are anaesthetised with carbon dioxide it reduces the period that elapses prior to the commencement of oviposition.

Pollen trapping

The study of the floral sources from which bees obtain their pollen has been continued by J. Simpson. In addition to daily collections of pollen, by means of a pollen trap, from a colony at Rothamsted, weekly collections were made by means of similar traps at a number of outside centres. The work of identification of the pollens collected is not yet complete but the results that have been obtained so far show several interesting features.

At Rothamsted by far the greatest yields of pollen were obtained from charlock and red clover. Between 27th May and 26th June 80 per cent. of the pollen came from charlock, while from 1st to 17th August practically nothing but red clover pollen was collected. In contrast to this scarcely any pollen was collected from white clover at any time during 1947. These features were also shown, though to a lesser degree, in the data obtained from other southern areas where trapping was carried out. On the other hand in a trap in Yorkshire a considerable amount of white clover pollen was obtained, but little red clover pollen.

Considerable quantities of pollen were also obtained in some areas from unexpected sources. In June large quantities of grass pollen were obtained in Essex, while in London at about the same time privet and chestnut were important sources of pollen.

Quantities of mixed loads containing pollen and fungal spores were collected on several occasions, which suggests that fungus was attacking the flowers from which the pollen was gathered.

The possible harmful effect of various herbicides on honeybees

Experiments designed to discover any possible effect of the recently developed selective herbicides on pollinating insects, particularly on the honeybee, were commenced by G. D. Glynne Jones in May, 1947. In preliminary laboratory experiments the two "hormone type" herbicides, M.C.P.A. (2-methyl-4-chlorophenoxyacetic acid) and D.C.P.A. (2:4 Di-chloro-phenoxy-acetic acid) were not found to act as contact poisons to the honeybee but they can act as stomach poisons. Dinitro-ortho-cresol and its sodium salt were found to be highly toxic to the honeybee both as contact and stomach poisons. DNOC and especially sodium dinitro-ortho-cresylate have been found to be repellent to the foraging honeybee. In glasshouse experiments a 1 per cent. solution of sodium dinitro-ortho-cresylate was found to be sufficiently repellent to prevent a hungry bee from feeding upon sugar syrup to which it had been added.

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Preliminary field experiments have indicated that poisoning of bees may be anticipated if the DNOC compounds are used to destroy charlock whilst it is actually in flower.

Sulphonamide treatment for American Foul Brood

Work on the use of sulphonamides for the treatment of colonies infected with American Foul Brood has been continued by P. S. Milne. It would seem that these drugs are unlikely to prove to be of such value in cases of this disease as had been hoped.

Adult bee diseases

A study is being made on the distribution of Nosema and Amoeba diseases. There is evidence that the incidence of Nosema disease has increased considerably. A further survey of the distribution of Acarine disease is also being made.

Bee breeding

Thanks to the discovery by Laidlaw of a new valve in the genitalia of the queen honeybee and modification by Mackensen and Roberts of Watson's technique of instrumental insemination, it is now possible to produce inseminated queens which are as satisfactory in their behaviour as naturally mated ones. This technique has been studied in detail at Rothamsted during 1947 and is now being applied successfully. The way now appears to be open to make a determined attempt to breed improved strains of bees for such purposes as the production of honey from various crops, the pollination of specific seed crops such as red clover, wax production, etc. It is intended to expand this work as quickly and as extensively as possible. Artificial insemination of queen bees will undoubtedly prove to be a most useful tool in the solution of many problems in bee research.

The effects of weather conditions upon honeybee activity

A study has now been made of the data obtained from the colonies of bees that have been kept on balances during the last twenty years. This material is now being prepared for publication.

Other studies

Observations have also been made on the methods of communiction practised by honeybees, home-finding and orientation, colony balance, etc.

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DEPARTMENT OF INSECTICIDES AND FUNGICIDES

By C. POTTER

Dr. Tattersfield retired from the headship of the department in June, 1947, but fortunately was able to continue working in the department on a part-time basis. Dr. Tattersfield's outstanding contributions to the field of research on insecticides and fungicides were recognised by the award of the O.B.E. in the birthday honours list.

Dr. Potter, who had spent the previous year in the United States of America as a Visiting Research Professor of Entomology at the invitation of the Rhode Island State College and the Connecticut Agricultural Experiment Station, spent the first two and a half months of 1947 in the U.S.A., touring research stations on behalf of the Agricultural Research Council. He returned to the department at the end of March and was appointed head of the department at the beginning of June.

For convenience the work of the department may be set out under five headings:—

(1) General and chemical
(2) Chemical
(3) Physico-chemical
(4) Biochemical
(5) Biological

(1) GENERAL AND CHEMICAL

Some of the newer organic insecticides have been examined. These include Velsicol 1068, Toxaphene and various samples of Hexaethyl tetraphosphate, which were primarily tested to investigate their direct contact effect. The samples of Hexaethyl tetraphosphate were examined at the request of the Agricultural Research Council and were worked on more extensively than the other two chemicals which gave rather disappointing results in preliminary trials.

Hexaethyl tetraphosphate has shown a high toxicity to the insect species under test and a small scale preliminary field test indicated that it was toxic to the active stages of the greenhouse red spider although it had little or no effect on the eggs of the mite. However, its very high toxicity to man is a factor militating against the use of this insecticide.

Some further work on the chemical and insecticidal properties of *Ryania speciosa* has been carried out. Extracts of this plant material have not shown any marked toxicity to the species of insect used, but as there is reason to believe that the toxic agents are rather specific in their effect the work is being continued. Mr. Lord has been responsible for a high proportion of this work.

Mr. Way made some preliminary trials on the stomach poison effect on the larvae of the tomato moth *Diataraxia oleracea* L. of four insecticides. He showed that the larvae of this species at the stage selected were completely unaffected by doses of Rotenone as high as 0·13 mg. per larva, thiodiphenylamine at 0·12 mg. per larva, the Triethanolamine salt of 3:5 dinitro-o-cresol at 0·044 mg. per larva and zinc fluoarsenate at 0·31 mg. per larva.

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As a result of work on the factors affecting the resistance of insects to insecticides, some of which is described later, it seems that the lepidopterous larvae used (*Diataraxia oleracea* L. and *Phlogophora meticulosa* L.) the stomach poison effect of DDT > γ –BHC > lead arsenate, and DDT is more effective than the gamma isomer of benzene hexachloride as a contact poison to these larvae.

Field experiments, statistically planned. A field experiment was carried out by Mr. M. J. Way to compare the efficiency of DDT and Benzene hexachloride for the control of pests of kale.

Two main treatments were carried out : (1) Drilling insecticidal dust with the seed and (2) Spraying and dusting kale seedlings after emergence. A study was made of seed germination, the emergence of seedlings and the growth of young plants.

No flea beetle infestation occurred and pest infestation generally was negligible in the two months following treatment. An analysis of the results showed that the insecticide treatments had conferred little benefit on the crop under these conditions.

Plots in which seeds were drilled with benzene hexachloride dust showed a slightly significantly higher proportion of emergence of seedlings than the DDT and control plots.

A further field experiment on the control of wireworms in Little Hoos field was started by Dr. Evans of the Entomology Department and Dr. Potter. The effect of DDT, Benzene hexachloride, Ethylene dibromide and the soil fumigant D.D. are being studied. The chemicals have been applied but the sampling has yet to be done.

(2) CHEMICAL

Collaborative work on the method of estimation of the pyrethrins has been continued and a number of slight variations in the mercury reduction method have been tested. Among the methods tried the use of n-hexane as a solvent instead of petroleum ether had been investigated and found to be satisfactory. The work is expected to continue with the department participating in a world collaborative scheme to compare the various methods and their modifications in use at the present time.

Mr. Lord has continued his study of DDT and 23 of its analogues and the alpha, beta, gamma and delta isomers of benzene hexachloride. Data on the toxicity of these compounds to the black chrysanthemum aphid *Macrosiphoniella sanborni* Gill. and *Oryzaephilus surinamensis* L. were obtained.

It was shown that the probit lines for the DDT analogues varied both in position and slope, those for the isomers of benzene hexachloride varied in position but not in slope. In general, neither the relative positions nor the relative slopes of the probit lines for the various substances were the same with the two species of insect.

The toxicity of the substances analogous to DDT appears to be related to molecular weight with a maximum occurring in the molecular weight range 300-450. Among the DDT analogues the slope of the probit line is apparently correlated with molecular volume as given by the parachor. It has been inferred that the variations in the slopes of the probit lines arises from differences in the interactions of the poisons with the test subject. It is also suggested that the evidence indicates that the action of DDT and benzene hexachloride have a reversible physico-chemical action rather than an irreversible chemical action.

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(3) PHYSICO-CHEMICAL WORK

Effect of particle size on the toxicity of suspensions of insecticide applied to the insect. Mr. McIntosh's previous work had shown that if the adult *Tribolium castaneum* Hbst. (flour beetle) is used as a test subject and dipping or spraying is used as the method of application, the toxicity of suspensions of DDT increases with increase of the crystal size of the DDT up to about 400μ. Crystals larger than this have not been tested. It has been found that the increase in toxicity is paralleled by an increased retention of the poison on the body of the insect. It is not suggested that this is the whole or even the major cause of the increase in toxicity.

Further tests were carried out using apterous viviparous females of the aphid *Macrosiphoniella sanborni* Gill. The results were unsatisfactory because considerable variation in both the absolute and relative toxicities was encountered. However, the evidence acquired indicated that a crystal size of $60 \times 15\mu$ was the least effective.

Rotenone. Using the dipping method and the adult saw-toothed grain beetle *Oryzaephilus surinamensis* L. as a test subject it was found that a decrease in the particle size resulted in an increase of toxicity and the magnitude of the particle size effect on toxicity far exceeds that obtained with DDT, over what is, if anything, a smaller range of sizes. A difference of 400 has been obtained between equal concentrations (w/v) of two suspensions of particles of two different sizes.

The results obtained to date indicate that crystal shape as apart from size have no demonstrable effect on toxicity of rotenone.

This work is being continued particularly with a view to explaining the results so far obtained.

By employing the methods he has developed here for preparing DDT suspensions of uniform crystal size Mr. McIntosh has prepared such crystals and mixed them with dust diluents, thus giving a series of dusts containing the toxic agent in a known and uniform shape and size. A number of these dust mixtures containing DDT crystals of various sizes in two diluents have been prepared for Dr. W. A. L. David of the Agricultural Research Council's Unit of Insect Physiology, Cambridge.

Sorption of DDT by chitin. Mr Lord has continued his studies on the sorption of DDT and its analogues by chitin. It has been shown that the amount sorbed is dependent on the surface area of the chitin and that sorption by the cuticle may be peculiar to the chitin since cellulose wool and silica powder do not possess this sorptive capacity for DDT and its analogues.

The rate of sorption and the amount sorbed is approximately the same for DDT as for its analogues.

(4) BIOCHEMICAL WORK

Mr. Lord has been continuing his work on the effect of insecticides on insect respiration using respirometers of a modified Barcroft pattern. The results of the initial experiments on the effect of insecticides on metabolism and death rate have been examined. The inferences drawn from the data are as follows. Toxic concentrations of DDT and its analogues applied as dusts to adult saw-toothed grain beetle *Oryzaephilus surinamensis* L. increase the rate

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of oxygen uptake. Sub-lethal concentrations have no effect. With groups of starving insects the total oxygen uptake from the time of exposure till death is the same whether or not the insect is treated with DDT or its analogues, insects treated with a lethal dose of insecticide respire more rapidly and therefore die sooner than untreated insects. The stimulus of DDT to this species is apparently quantal in nature and the magnitude is independent of the concentration of DDT in the dust applied. The stimuli resulting from the action of DDT and its analogues are approximately equal, as are the rates at which the insects die.

The effect of Benzene hexachloride on adult *Oryzaephilus surinamensis* L. has been shown to be similar to that of DDT.

The qualitative effects of some other insecticides have been observed and it has been found that Rotenone and Lethane 371 depress the oxygen consumption while 3:5 dinitro-o-cresol causes the death of the insect far more rapidly than any other poison investigated.

This work is being continued. Modifications of the apparatus for the application of the poison *in situ* are being studied.

During the course of his work on the relationship between the weight of the insect and its susceptibility, Mr. Way carried out some work on the changes that occurred with larvae of tomato moth *Diataraxia oleracea* L. poisoned with DDT. Detailed studies were made of the total loss in weight, of the change in moisture content, and the change in dry weight during DDT poisoning. Over 60 per cent. loss of water occurred between the time of poisoning and death. The dry weight decreased by 3–4 per cent. and of this only 0·5 per cent. was loss in fat content.

Thus although 4–5 days may elapse before death occurs and during this period the larva is continuously active, fat does not appear to be utilised as a source of energy. Experiments showed that an untreated but starved larva utilised its stored fats.

(5) Biological

Factors affecting the susceptibility of insects to insecticides

(a) Effect of larval body weight on resistance.

During the latter part of 1946 and early 1947 Mr. M. J. Way made a detailed study of the relationship between larval body weight and the resistance of the larvae to various insecticides.

Preliminary studies with the last instar larvae of the tomato moth *Diataraxia oleracea* L. showed that as the larvae increased in weight so its resistance to stomach poisons increased. The extent of the increase varied with the insecticide used.

With lead arsenate, using larvae of weights from 0·15 gm. to 0·55 gm., there was a constant relationship between increase of weight and increase in resistance if the weight increase was x 2 the Median lethal dose had to be multiplied by 1·3.

With DDT the problem was not so simple and there is not a straight line relationship between increase in body weight and increase in resistance. There is a greater increase in resistance per unit increase in body weight at the higher larval weights than at the lower larval weights, e.g., if the larval weight is increased from 0·15 gm. to 0·30 gm. the median lethal dose increases from 0·00075 mg. per larva to 0·0030 mg. per larva, an increase of

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0·015 mg. per gram; if, however, the larval weight increases from 0·45–0·55 gm. the m.l.d. increases from 0·0175–0·0440 mg. per larva, an increase of 0·265 mg. per gram.

The gamma isomer of benzene hexachloride showed a similar relationship to DDT but the changes were not so strongly marked.

These results were obtained using a technique for studying stomach poison action in which contact action was eliminated as far as possible.

A study was then made along the same lines on the effect of body weight on contact toxicity using DDT and the gamma isomer of benzene hexachloride. The dose per larva was determined by washing the insecticide from the larvae with benzene after spraying and estimating the amounts colorimetrically.

A similar relationship between body weight and resistance was found when the insecticides were applied as contact poisons as had been found when they were applied as stomach poisons although there were some differences in degree.

An interesting aspect of this comparison was that DDT proved to be more toxic as a contact poison than as a stomach poison if the amount retained on the body (producing a given percentage kill) is compared with the amount required to be ingested to produce the same kill. This can only be said to be true of this particular set of experiments.

This study with lepidopterous larvae on the relationship between body weight and resistance has proved very important in assessing the validity and significance of estimations and comparisons of toxicity. It seems probable that for stomach poisons at least, where it is only possible to use relatively small numbers of insects, estimates must be made by measuring the three variables, dose, body weight and mortality and the results analysed by the probit plane technique. It is hoped to continue this work later on.

Another item of interest brought out in the course of this work was that with the last instar larvae of tomato moth there was a sudden fall in resistance to the gamma isomer of benzene hexachloride just prior to pupation.

(b) Cuticular structure and the penetration of insecticides.

Toward the end of April, 1947, Mr. Way was seconded to the Entomology Department, Cambridge, under the direction of Dr. V. B. Wigglesworth where he commenced to work on the penetration of insecticides through the cuticle using larvae of the tomato moth as test subjects. This work is still in progress. Developmental changes in the structure of the cuticle have been studied and, as with other insects, complex structure is apparent. The cuticle consists in general of five layers of different composition which are all already present at the beginning of the last instar but which increase in thickness and change in composition during the development of the instar. In certain areas of the body wall the cuticle is specialised and may be thin with several of the layers missing. The cuticle overlying sense organs and certain areas of the prolegs and muscle insertions are examples of these areas. It would appear that the penetration of poison could occur most readily in these areas.

The difficulty of developing a technique whereby droplets of

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insecticide can be placed and confined in particular areas of cuticle resulted in the failure of many attempts to determine the rate of penetration in particular areas of the cuticle, all that can be said is that with the insect under test the penetration of DDT in certain parts of the body is very slow or does not occur at all. The head and tail regions seem more sensitive than the middle regions of the body.

(c) The effect of environment on toxicity.

Mr. McIntosh found in the course of his experiments that rotenone gave a higher kill of adult *Oryzaephilus surinamensis* L. when the insects were kept after treatment at 32° C. than at 20° C., while the reverse effect was found when DDT was used.

Dr. Pradhan has been studying the effect of changes in the environment on the toxicity of residual films of insecticide.

A study was first made of the relationship between the concentration of insecticide, the time of exposure and the mortality produced.

Various techniques were worked out to ensure continuous contact between the insect and the insecticide film.

At first when adult flour beetle *Tribolium castaneum* Hbst., which does not climb on glass surfaces were used as test subjects and DDT as insecticide, films were made on filter papers and the insects confined on the films by means of inverted whole filter funnels. When the gamma isomer of benzene hexachloride (γ–BHC) was used as insecticide there was evidence of a fumigant effect with this technique and the stems and part of the cone of the funnel was cut off so that free aeration could occur, rings of glass cut from glass tubes 4–5 cms. diam. were also used. When the larvae of the diamond back moth *Plutella maculipennis* Curt. were used as a test subjects and DDT as insecticide equal films were formed on two filter papers; then one of the papers was folded into a cone by a standard technique with the film on the inner surface of the cone, the cone was then inverted over the unfolded filter paper to form an enclosure, all surfaces of which were coated with insecticide, the insects were confined in this enclosure. The cone was kept in position by a circular iron ring. When γ–BHC was substituted for the DDT, at first the cone of filter paper was perforated to allow for aeration but this proved unsatisfactory and finally a similar arrangement was adopted to that used with DDT but bolting silk was used throughout instead of filter paper.

The variation in mortality with changes in concentration and exposure time was studied using adult *Tribolium castaneum* Hbst., larval *Plutella maculipennis* Curt. and nymphs of the black chrysanthemum aphid *Macrosiphoniella sanborni* Gill. DDT was first used and then γ–BHC. The adult *T. castaneum* proved the best test subject.

It was found that at a given temperature (80° F.), if the insects were given a short exposure time (24 hrs.) and examined immediately zero mortality was obtained at all the concentrations tested, thus producing a straight line curve parallel to the Y axis at zero mortality. At the other extreme with long exposures (36 days) 100 per cent. mortality was obtained at all the concentrations tested in cluding controls, giving a straight line curve parallel to the

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Y axis at 100 per cent. mortality. Intermediate exposures (all followed by immediate examination) gave curves of various shapes, for the most part sigmoid in character. This data also shows that as the strength of the film increases the average survival period on the film goes on gradually decreasing.

Some preliminary studies of the effect on toxicity of the surface on which the insecticidal film is formed were also made using both DDT and γ–BHC. The surfaces tested were glass, paraffin wax, filter paper, bolting silk, geum leaf, marrow leaf, cabbage leaf and leaves of water lily. It was found that films on waxy surfaces such as paraffin wax and leaves of water lily and cabbage were relatively non-toxic compared with glass and leaves of geum. An extensive series of experiments were then carried out to determine the effect of temperature on mortality of insects exposed to films of insecticide using adult *Tribolium castaneum* Hbst. and larval *Plutella maculipennis* Curt. From the results of these experiments together with a survey of the literature the following generalisations were inferred:

(a) That insect resistance to poisons changes with temperature as do its other vital activities, i.e., increasing up to a critical point and then decreasing.

(b) With insecticidal films the amount of poison reaching the site of action in unit time also varies with the temperature, generally, but not always, increasing with increased activity of the insect. The locomotor activity of the insect appears to play an important part in the pick-up of the insecticide. An instance where increased activity appears to result in decreased pick-up occurred with larvae of *Plutella maculipennis* Curt. where the web spun by the larvae as they moved formed a protective layer on the surface of the film.

(c) The overall effect of temperature on the insecticidal action of films is the result of the interaction between the two preceding factors, resistance and pick-up.

Finally some investigations were made on the effect of changes in relative humidity on the mortality of insects exposed to films of insecticide. In this series adult *Tribolium castaneum* Hbst. and the larvae of *Plutella maculipennis* Curt. were again used as test subjects. The two insecticides studied were DDT and 3:5-dinitro-o-cresol (DNOC).

With the adult *T. castaneum* the toxicity of both DDT and DNOC increases with increased relative humidity. This is true both during the course of exposure and after treatment.

However, when the larvae of *Plutella maculipennis* Curt. are exposed to the film for 24 hours and then inspected at once and the mortality assessed, it was found that increased relative humidity resulted in a decreased mortality with DDT films but increased mortality with films of DNOC.

No general principles could be deduced from the latter experiments and a survey of the literature. However, it seems likely that factors that must be taken into consideration besides that of the species and instar of insect and the nature of the insecticide, are the concentration of the insecticides used, the effect of humidity being discernible at some concentrations and not at others, and the range of humidity; differences may not show unless a wide range of humidities are tested.

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Partly owing to the absence of Dr. Potter and partly owing to pressure of other work, only a little data was acquired on long term fluctuation of resistance, this work was done by Mrs. Gillham. Studies on the effect of environment on insect resistance apart from those carried out by Dr. Pradhan were also held up partly for the reasons given above but chiefly owing to lack of facilities for producing a controlled environment.

Insect rearing. In connection with this proposed work on rearing insects in an environment where temperature, humidity and light are controlled, Miss R. I. Stoker carried out some preliminary experiments on the effect of these conditions on plant growth. Three different illumination units were installed in a constant temperature room and controlled by means of time switches to give 14 hours light and 10 hours darkness. Unit (1) consisted of four 80 watt daylight fluorescent tubes. Unit (2) consisted of two 80 watt daylight fluorescent tubes and one 400 watt neon tube. Unit (3) consisted of two 400 watt neon tubes. The temperature of the room was approximately 27° C., the humidity was not strictly controlled.

Turnips were used as test plants. No difference was observed in germination rate but from then on there was a steady improvement in the growth and condition of the seedlings under the neon lights as compared with the fluorescent lights. The most noticeable difference was in leaf colour and size, the neon lights producing larger leaves of a darker green colour. The plants grown under the combined lights (Unit 2) gave plants rather less vigorous than the neon lights but similar in colour and texture. There were temperature differences between the units due to the large amount of heat produced by the neon lights, but this is not thought to account for the observed differences.

Many difficulties were encountered in this work owing to lack of facilities for temperature and humidity control and to frequent failures of the electricity supply but it is very much hoped that we shall be enabled to remedy these deficiencies and carry on with the work.

A considerable amount of work was carried out on the rearing of insects. The species now in regular use as test subjects were studied in order to improve the rearing techniques and additional species which might prove useful were investigated.

The ordered progress of this work also was handicapped by lack of facilities for illumination and controlled environment.

Phaedon cochleariae *F*. (*Mustard beetle*). Miss R. I. Stoker has made a detailed study of the laboratory rearing of mustard beetle. Besides being the only beetle of agricultural importance which has so far been found suitable for laboratory rearing, it has many good qualities as an experimental animal, among which are convenient size, ease of handling, absence of disease, and a host plant that can be made available throughout the year.

Detailed studies have been made on the fecundity of the adults, the viability of the eggs and the development of the larvae, pupae and adults under various conditions of lighting in the constant temperature room. It has been found that while the insect cannot be reared throughout the year in the glasshouse with natural illumination it is possible to do this in the constant temperature

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room with illumination from either neon or fluorescent lights. The evidence to date suggests that the diapause does not occur with insects reared continuously at 75° F. with illumination as previously described for 14 hours per day.

The major difficulty at present is the great variation in the fecundity of the adults. Experiments have been made to determine the factors affecting egg-laying, so far with no positive results. The work is being continued.

Myzus persicae *Sulz.* Mrs. E. M. Gillham has carried out some work to compare the rates of reproduction of this aphid under three different lighting conditions at approximately constant temperature with that occurring under greenhouse conditions where there were great variations in temperature and illumination. Considerable difficulties were again encountered due to deficiencies in the apparatus and failure of the electricity supply. In addition, the insects were difficult to handle. The general indications were that over the period during which data were collected there was no significant difference between the number of young produced under the various conditions although it was usually slightly lower under glasshouse conditions. This work is only preliminary and it is hoped to undertake more detailed work if the necessary staff is available. Stocks are kept going all the year round on cabbage and turnip.

Macrosiphoniella sanborni *Gill.* (*Black chrysanthemum aphid*). This aphid can now be reared under glasshouse conditions for most of the year but there are periods in midsummer and midwinter when it is difficult to rear in numbers. Facilities for added illumination might overcome this difficulty. It is our most useful test aphid.

Macrosiphum solanifolii *Ash.* (*Green potato aphid*). This is a most valuable aphid for test purposes because it is easily handled, it lives several days with food and is, in general, resistant.

So far, however, we have found it difficult to rear continuously in numbers in spite of its wide range of host plants. It is rather susceptible to fungus disease.

Work on this species is being continued.

Acrythosiphon onabrychia [Macrosiphum pisi] (*Pea aphid*). This insect is being reared because some evidence was obtained that its resistance varied with the host plant on which it fed. However, we do not know enough about its biology to rear it successfully. It was found in one season that cultures on broad bean remained viviparous throughout the winter in the cool glasshouse while in another season when it was reared on clover it produced oviparous females in October and remained in the egg stage throughout the winter. It is hoped to find a suitable technique for rearing this insect.

Aphis fabae *Scop.* (*Bean aphid*). Considerable difficulties are now recognised to exist in the identification of this insect. At present we rear a species obtained from nasturtiums which is continuously cultured on that host. It appears to be a distinct species, as yet unnamed, and attempts to establish it on broad bean have so far been unsuccessful although it will colonise dock.

Cultures can be maintained on nasturtiums throughout the year but during the winter months reproduction is very slow under

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glasshouse conditions, and again facilities for a controlled environment, including illumination, would be a great help. The insect is a very useful general test subject.

Myzus circumflexus *Buct.* This insect can be reared throughout the year on Arum lily (Richardia) and has proved a useful supplementary test subject.

Plutella maculipennis *Curt.* (*Diamond back moth*). This insect is reared all the year round in large numbers on cabbage and turnip. There is a complete absence of seasonal rhythm. The technique of rearing has been fully studied and this is probably the most easily reared in numbers of all the mandibulate species. It is used as a test subject for most phases of our work.

Diataraxia (Polia) oleracea *L.* (*Tomato moth*). This insect is used a great deal for stomach poison studies and other work. It is reared in large numbers on dock, cabbage and turnip. It normally has a diapause but this may be broken by (a) Rearing for the latter part of larval life under fluorescent lighting for 15 hours per diem, or (b) Keeping the pupae in a refrigerator for a minimum period of two months. So far 11–12 generations have been reared from the same stock at the rate of about 6 generations a year without serious trouble.

Xanthorhoe fluctuata *L.* (*Garden carpet moth*). This moth can be reared in large numbers on cabbage and turnip throughout the year. The normal diapause can be broken by refrigerating the pupae for a minimum of two months. It has not so far been widely used because it is not an economic pest.

Mamestra brassicae *L.* (*Cabbage moth*). This has been reared in large numbers on cabbage and turnip but shows more difficulty with diapause and disease than tomato moth. However, the pupae may be refrigerated for a year at least and brought out at any time to continue the life cycle.

Agrotis segetum *Schiff* (*Turnip moth*). The rearing of this species has been abandoned owing to its susceptibility to disease.

Phlogophora meticulosa *L.* (*Angle Shade*^{s} *moth*) This species can be reared in large numbers using the foliage of most low plants as food. The data are not yet complete on methods of rearing throughout the year. The diapause can be broken, but all eggs laid by moths emerging in November proved to be sterile.

Abraxas grossulariata *L.* (*Magpie moth*). Work has been started on this species but no means has as yet been found for breaking the diapause.

Porthetria dispar *L.* (*Gypsy moth*). This insect has certain advantages as an experimental subject. The male and female larvae can be separated. There has been no trouble with disease and its polyphagous habits make it suitable for studies on the effect of host plant in resistance. However, since it feeds on deciduous plants it may not be reared all the year round. It has been found that by storing the eggs in a refrigerator and bringing them out at intervals during the late spring and summer, several generations of the moth can be reared in a year.

Sphinx ligustri *L.* (*Privet Hawk moth*). This insect is reared because its large size make it a suitable insect for special studies. It has been reared on privet, lilac and ash, but all attempts made to break the diapause so far have failed.

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Cerura (Dicranura) vinula *L.* (*Puss moth*). This insect has been reared on willow and poplar but it is not thought to be a useful test animal.

Odonestis (Cosmotriche) potatoria *L.* (*Drinker moth*). This has been reared in small numbers on coarse grass but does not appear to be a likely subject. An attempt to break the diapause was unsuccessful.

Artia caja *L.* (*Garden tiger moth*). This insect has been reared on dock, cabbage and other plants. An unsuccessful attempt to produce a strain without a diapause was made by rearing at a constant temperature of 75° F. Further work may be done on this species.

Athalia colibri (*Turnip sawfly*). Since no hymenopterous pest was available as a test insect, rearing work was started on this species. Little data are as yet available but breeding under fluorescent lights broke the diapause on one occasion.

EFFECT OF HERBICIDES ON BEES

Mr. G. D. Glynne-Jones was seconded from the National Advisory Service in May, 1947, to work conjointly with the Insecticides Department and the Bee Department on the effect of herbicides on bees.

Preliminary experiments with proprietary herbicides showed that, at field strength, herbicides containing Dinitro-o-cresol were highly toxic both as stomach and as contact poisons to bees. Proprietary herbicides containing 2-Methyl-4-chloro-phenoxyacetic acid (MCPA) (hormone type) showed no evidence of contact effect at field strengths but some evidence of stomach poisoning effect.

Some work was then carried out to obtain a suitable laboratory technique for quantitative studies. By means of these techniques it was ascertained that the median lethal dose (m.l.d.) of sodium-dinitro-o-cresylate as a stomach poison to bees lay between 0·0020 and 0·0025 mg. per bee. It was further found that the m.l.d.'s as a stomach poison for 2–4 dichloro-phenoxy-acetic acid (DCPA) and its sodium salt were about the same and lay between 0·002 and 0·005 mg. per bee. A stable suspension of MCPA could not be prepared, but the toxicity of the sodium salt was similar to DCPA and its sodium salt.

Experiments on the contact poison effect showed the m.l.d. of DNOC to be 0·0025 mg./sq. cm. at 30° C. and of its sodium salt to be 0·0035 mg./sq. cm. at 30° C. The conditions of the test greatly affect the toxicity. MCPA and DCPA proved non-toxic at all the concentrations tested.

Experiments made by exposing bees to residual films of DNOC and its sodium salt showed that the conditions, particularly humidity, greatly affected the results, kills varying from zero to 100 per cent. mortality were recorded.

A series of experiments were made on the attractant, or repellent properties of DNOC and its sodium and ammonium salts. The general evidence was that these substances are repellent.

The overall evidence is that DNOC and its salts when applied as weedkillers are a potential danger to bees, particularly if applied to open blossom, the "hormone" type weedkillers are safer. Further work is required, especially in the field, before any very definite statements can be made.

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FIELD EXPERIMENTS ON THE ROTHAMSTED FARM

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

From the point of view of the field experiments 1947 was an unfavourable year. Wheat and beans were drilled under rather sticky conditions and made very slow progress. At the end of January the great frost set in and lasted till the middle of March. Although the ground was snow-covered wheat and beans suffered badly. Both the bean experiments on Stackyard field were lost, most of the wheat on Agdell field failed, and an experiment put down on Delharding to test the effect of spring mowing on winter-proud wheat was abandoned although the wheat was not actually killed. When the snow cleared the land remained very wet for some weeks. Spring cereals were not drilled till mid-April nor potatoes planted till the end of May. Growth in early summer was very rapid, however, and the heat and drought which set in in July brought on the corn unusually quickly to harvest. No rain came for potatoes which looked very vigorous in the haulm but nevertheless made a rather light crop. Sugar beet grew well but the plant population was low and irregular. The real disappointment of the year was wheat which was the worst crop for many years. Other crops though somewhat below average were reasonably good.

The number of plots handled by the Field Staff in 1947 is shown in the following table:—

	Cereals and beans	Potatoes and roots	Hay	Grazing	Total
Classical	113	72	47	—	232
Long Period Rotations, etc.	215	232	56	9	512
Annual Experiments ...	321	414	—	—	735
	649	718	103	9	1,479

The total number of plots in 1946 was 1,554.

The winter failure of the beans and wheat accounted for the loss of 128 plots, so that the actual number harvested in 1947 was 1,351.

The classical fields

Broadbalk. The field was drilled at the end of October in a rather sticky seed-bed. When the snow melted in spring Section V, which is near the drain and carried the fourth crop after fallow, was badly washed. The wheat never recovered and looked poor throughout the season, with much Slender Foxtail. In fact this part of the field was very similar to the Broadbalk of the pre-fallowing days. None of the other sections were good in 1947, straw was short and there was no lodging. Wild oats were plentiful, but a thorough hand pulling by a gang of German prisoners as soon as the oats topped the wheat made a very good job of the field.

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The wild oats, always worse on the dunged plot on the North side of the field, are gradually spreading southwards and have now reached as far as plot 11.

Great Hoos wheat and fallow. The wheat was the poorest crop for many years. It was thin, straggled, and the ears were very small. The crop was very little better than the unmanured plot on Broadbalk Section V.

Hoosfield. The permanent barley plots were sown on 17th April (on only three occasions in the long history of the field had drilling been so late) and even then the crop was slow to grow away owing to drought. The plots were sprayed with "denocate" quite successfully to reduce broad-leaved weeds, but as in former years the most serious trouble was wild oats. In an attempt to check this weed the same harvesting procedure was adopted as in 1946. On those plots where the infestation was slight the oats were carefully hand-pulled and the barley was cut and harvested in the usual way. Where the oats were too thick for hand-pulling all but a small fraction of each plot was cut green and the produce disposed of, the oats on the remaining area were carefully hand-pulled and the barley allowed to ripen to give an estimate of yield.

Barnfield. Dr. Peters, of the Institute of Agricultural Parasitology, St. Albans, reported on the eelworm infestation of Barnfield as estimated from cyst counts made in soil samples taken after the crop of 1946 had been lifted. The conclusion was that the infestation had not yet reached serious proportions. It was therefore decided that cropping with mangolds and sugar beet should be continued.

The land lay very wet in spring and cultivation could not begin till mid-April. Four rows of sugar beet were again sown on each of the mangold plots. The mangolds were a poor crop. The highest yield (dung and complete fertilisers) was only 14·4 tons per acre, and the plant population was low at about 15,000 per acre. The sugar beet appeared to stand up to the long drought rather better: yields ran up to 8·2 tons where the plots were fully manured, but there were only 16,000 plants per acre. Conditions for lifting the crop were excellent. A fungus disease Phoma Betae was very prevalent on the roots of the sugar beet, particularly on the plots receiving sulphate of ammonia. The mangolds were not affected.

Park Grass. Growth started very late on the grass plots, and owing to pressure of other work the first spring dressings of nitrogen could not be applied till 15th May and the second dressings till 29th May. Nevertheless in June growth was very rapid and the crop, though in general lighter than average, was very much better than might have been expected; indeed the unmanured plots and plot 7, Minerals only, gave well above their average yields. The hay was cut on 12th June.

Agdell. Most of the wheat failed on this field. On the fallow section practically none was found after the snow melted, the adjacent side of the clover strip carried an exceedingly poor plant, but the east side of the clover section nearest Harwoods Piece

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carried a reasonably good plant. This plant was left, but the whole of the fallow section and the remaining half of the clover section was drilled with spring wheat.

Long-period experiments

Four-course rotation. This experiment tests the first year and residual effects of dung, straw compost, and raw straw plus fertiliser, and also of superphosphate and rock phosphate. The cropping is potatoes, barley, ryegrass, wheat. The results of the first 13 years cropping were summarised in the Station Report for 1946.

The wheat of 1947 was the poorest crop ever grown in this experiment, the mean yield being only 8·5 cwt. per acre. There was a good plant in the autumn but the crop wintered out very badly. In particular certain plots treated with rock phosphate in previous years practically failed. The ground was too wet in the autumn to make the usual sowing of ryegrass; the seed was put in in spring, 12th April, and growth was so small at the time of cutting that very light hay yields were obtained. The potatoes started in an unusually good tilth but suffered from drought before the end of the season. Barley was an even crop but rather below average.

Six-course rotation. This experiment tests 5 levels of each of the three main nutrients, N, P, and K applied direct to every crop of the rotation sugar beet, barley, clover, wheat, potatoes, rye.

Clover was very good in this rotation, most crops were up to the average but rye was poorer than usual, the straw being about a foot below the average height. Sugar beet was a rather gappy plant and gave only 4 tons of tops per acre.

Two-course rotation. The main point under test in this rotation of sugar beet and barley is the cumulative effect of dressings of agricultural salt when applied to the same plots year after year. There are also comparisons of salt and muriate of potash.

In 1947 the barley was fairly good and as usual showed little effect either from applications of salt or from residual potash. The sugar beet was rather a thin plant, except where 5 or 7½ cwt. of salt per acre had been applied, and the crop was much below the usual level. Salt again appeared to be much more effective than muriate of potash.

Highfield grazing experiment. This experiment carried out for the Royal Agricultural Society of England to measure the manurial value of cake fed on pasture is nearing the end of its third cycle. The first-year effect of cake feeding has been measured as live-weight increase of cattle and sheep, three times on each of the three cake-treated plots, and only the figures for 1948 are required to complete the corresponding nine measurements of second-year effects.

There could hardly be a greater contrast in weather between 1946 and 1947, the first was exceptionally wet in summer and the second exceptionally dry, nevertheless the gains made on the plots during the grazing season were similar.

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The unmanured plot No. 9 in block III is comparable for the two years in question and gives the following figures:—

	1946	1947
Live-weight increase lb. per acre		
Cattle	278	319
Sheep	66	38
Total	344	357
Starch equivalent lb. per acre		
Cattle	1,254	1,409
Sheep	712	383
Total	1,966	1,792
Grazing days per acre		
Cattle	108	123
Sheep	309	180
Grazing period		
Cattle	May 9–Oct. 31	May 15–Sept. 18
Sheep	June 5–Nov. 28	June 11–Nov. 25

In the wet year the grass carried a higher sheep-stock and carried the cattle longer in autumn, but the starch equivalent and live-weight increase were similar in the two years, as they are largely determined by the amount of herbage produced early in the season.

The mean yields of starch equivalent and the mean live-weight increases over two seasons following the feeding of cake and the application of the conventional fertiliser equivalent of the cake averaged over the eight years of the experiment were as follows:—

	Starch equivalent cwt. per acre	Live-weight increase cwt. per acre
No cake or fertilisers ...	14·1	2·6
Fertilisers	15·4	2·7
Cake feeding	15·5	2·9

Deep-cultivation rotation experiment. This experiment, begun in 1944, consists of 6 blocks cropped with sugar beet, barley, seeds, wheat, potatoes, oats respectively, with the crops rotating on the blocks in the above order. In each block there are 16 plots testing all combinations of the following pairs of factors: 7 v. 14 inch ploughing, 0 v. dung, 0 v. superphosphate, 0 v. muriate of potash.

Deep ploughing is given for sugar beet, wheat, and potatoes. Dung is given to sugar beet (10 tons) and potatoes (20 tons), and these crops also receive the phosphate and potash treatments. The contrasted ploughings are given for the sugar beet, wheat and potato crops. All dung is applied before these ploughings, but the phosphate and potash are ploughed down on half of the plots and applied on the surface or in the drills on the other half.

In 1947 deep ploughing gave somewhat better yields of potatoes on plots receiving potash in the drills. Deep ploughing gave spectacular improvements in the sugar beet, the average increase on deep-ploughed over shallow-ploughed plots being 3·2 tons washed roots, 1·7 tons tops and 12·4 cwt. sugar per acre. This

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gain from deep ploughing was attributed largely to the fact that the deep-ploughed plots were clean early in the season when the shallow-ploughed ones carried a very heavy crop of annual weeds. After weeding and singling the plants on the deep-ploughed land showed much more vigorous growth, the difference persisting throughout June and July.

THE ANNUAL EXPERIMENTS

1. *Potatoes. Organic manures.* An experiment testing eleven different kinds of bulky organic manures, each at two levels and in the presence and absence of the three standard fertilisers has been conducted each year from 1940 to 1946 in three 5 × 5 lattice squares with each main plot divided into quarters making 300 sub-plots. In 1947 a similar experiment was carried out on 150 sub-plots, the phosphate test being omitted. Nine farmyard manures of known history and composition, a bracken compost and raw straw were tested. Single dressings of all farmyard manures gave increases between 10 and 30 cwt. per acre. The double dressings of the well-rotted manures showed further increases but the double dressings of the fresh strawy manures gave poorer results than the single dressings. The bad effect of incorporating dry bulky material in the ridges in a dry summer was seen in an aggravated form with raw straw which at the double rate seriously reduced the crop even where sulphate of ammonia was applied with the straw.

2. *Potatoes. Time of planting. Fertilisers.* This annual experiment has with minor modifications been conducted since 1945, its primary purpose being to provide the Plant Pathology Department with material for the field study of the spread of virus diseases. Normally the experiment tests dung, nitrogen, phosphate and potash in relation to four times of planting. In 1947 owing to the late season the planting times were reduced to two, and the phosphate comparison was omitted. There was no early planting in the ordinary sense of the word, the first possible date was 5th May and the late planting was carried out on 27th May. Farmyard manure behaved very differently according to the time of planting of the tubers. On the "early" planting dung was quite effective, giving an increase of 2·46 tons of potatoes in the absence of potash; on the later-planted potatoes dung had practically no effect: it increased the yield, even in the absence of potash, only by 0·7 tons per acre.

3. *Potatoes. Cultivation experiment.* The factors tested in this experiment were earthing-up, depth of inter-row cultivation, and the application of a straw mulch between the rows. In addition, the fertiliser was either broadcast before drawing the drills or applied in the ridges before planting. With yields in the neighbourhood of 8 tons per acre none of the treatments showed marked or consistent effects.

4. *Potatoes. Residual values of applications of organic manures over seven seasons.* This experiment on dung, town refuse, fermented town refuse and screened dust began in 1940 and until 1947 carried crops of sugar beet, mangolds, barley, beans, wheat and sugar beet. Over this period the bulky manures applied amounted

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to 56 tons per acre. The plots also tested the effects of muriate of potash and sulphate of ammonia applied annually. In 1947 no organic manures were given and potatoes were grown to test the residual effects. The residues from dung increased the crop by 2·2 tons per acre, those from screened dust by 0·9 tons per acre, and those from composted town refuse by 0·5 tons per acre.

5. *Potatoes. Fertiliser placement.* This experiment formed one of a series of ten. Growth was seriously checked by placing the fertiliser in a band in direct contact with the sets. The best yields were obtained from side-band placement, though on the average of all ten experiments this method had little advantage over broadcasting after ridging.

6. *Sugar beet. Fertiliser placement.* Placing fertilisers 2 in. below the seed and at either 0, 1 or 3 in. to the side gave better yields than broadcasting the fertilisers. In seven parallel experiments elsewhere different results were obtained, localised placement often being inferior to broadcasting.

7. *Wheat. Residuals from bulky organic manures applied to potatoes in* 1946. A good crop of Bersee wheat showed no residual effects from farmyard manures applied to potatoes in 1946 at rates of about 8 and 16 tons per acre.

8. *Wheat. Eyespot experiment.* The effects of rate and depth of sowing, nitrogen and spraying with sulphuric acid on eyespot, lodging and yield of wheat were tested for the second year. The late dry season (contrasting with 1946) resulted in exceptionally low eyespot incidence and very short straw; there was no lodging but weeds were unusually prevalent. Spraying reduced eyespot and greatly reduced weeds; it increased yield by 1·6 cwt. per acre. Increased rates of sowing from 1 to 2 and 3 bushels per acre increased yields only where nitrogen was applied. Both 2 and 4 cwt. sulphate of ammonia gave increased yields.

9. *Spring-sown cereals.* The yields and fertiliser responses of four spring-sown cereals were tested for the first time in 1947. Atle wheat, Plumage Archer barley, Star oats and Bersee autumn wheat were all sown on 12th April and received test dressings of 0, 0·3, 0·6, 0·9 cwt. N per acre as sulphate of ammonia, and 0 and 0·6 cwt. P_2O_5 per acre as superphosphate, 0 and 0·6 cwt. K_2O per acre as muriate of potash. All crops grew very well and responded well to nitrogen. The wheats and oats stood up at harvest but part of the barley was lodged. The responses to the heaviest dressings of nitrogen were: oats 9·4 cwt., Atle wheat 5·4 cwt., Bersee wheat 5·2 cwt. and barley 3·7 cwt. per acre. The barley showed a good response to potash and the oats to phosphate.

10. *Three-course rotation experiment on the use of straw.* Several experiments of both long and short terms have been carried out in recent years to test various methods of utilising straw on the land. The Rothamsted Report for 1946 contains a summary of the results of a four-course experiment started in 1930. A similar summary is given below for a three-course experiment commenced in 1933 in Long Hoos Field, Section VI.

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The main purpose of the experiment is to study the immediate, residual and cumulative effects of straw-ploughed in and made into compost. All plots receive equal amounts of N, P, K fertilisers; half of the plots receive raw straw in addition and one-quarter receive a compost made from the straw and the fertilisers. The treatments tested are:—

Ar Fertilisers only, no organic manure
Ad Straw made into compost and applied in autumn
St1 Raw straw ploughed-in in autumn, fertilisers in spring
St2 Raw straw ploughed-in in autumn, half the fertilisers applied in autumn and the remainder in spring.

These treatments are applied to their respective plots in alternate years, so that both the immediate and the residual effects are measured. The eight treatments are repeated three times in each block. There are three blocks cropped with potatoes, barley, sugar beet, which follow one another in that order. The straw applied directly to the land or used to make compost is at the rate of 53·3 cwt. per acre. The fertilisers provide 0·4 cwt. N, 0·4 cwt. P_2O_5 and 0·5 cwt. K_2O per acre. On the compost plots the whole of the nitrogen and phosphate fertilisers are used to rot the straw, the potash fertiliser being applied separately in spring. In addition to these treatments all sugar beet plots receive 0·2 cwt. N, 0·2 cwt. P_2O_5 and 0·25 cwt. K_2O per acre, and all potato plots double these amounts.

The average yields over fourteen seasons are given below:—

3-course rotation experiment—Rothamsted
Mean yields per acre, 1934 *to* 1947, *inclusive.*

		Potatoes	Barley		Sugar Beet		
			Grain	Straw	Washed Roots	Tops	Sugar
		tons	cwt.	cwt.	tons	tons	cwt.
Immediate effects							
Yields in year of application							
Ar	No straw	9·15	32·3	37·4	11·60	10·63	43·5
Ad	Straw-compost ...	7·89	27·6	29·8	9·88	8·09	37·3
St1	Raw straw, fertilisers in spring	9·70	30·8	34·5	10·91	9·32	41·4
St2	Raw straw, fertilisers in autumn & spring	9·20	30·7	32·8	11·05	9·29	42·0
	Mean ...	8·99	30·4	33·6	10·86	9·33	41·1
Residual effects							
Yields in year after application							
Ar	No straw	6·95	27·4	29·1	10·07	8·16	38·0
Ad	Straw-compost ...	7·42	26·0	28·3	9·78	8·11	36·9
St1	Raw straw, fertilisers in spring	7·97	26·9	29·0	10·13	7·84	38·2
St2	Raw straw, fertilisers in autumn & spring	7·96	27·8	29·9	10·30	8·36	39·1
	Mean ...	7·58	27·0	29·1	10·07	8·12	38·1

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In the year of application both raw straw and straw compost reduced the yields of barley and sugar beet. The reduction was particularly noticeable in barley straw and sugar beet tops, both of which are sensitive to the supply of available nitrogen. These results show that straw locked up some of the fertiliser nitrogen in forms which did not become available to the immediately following crop.

In the year of application potatoes gave different results from barley and sugar beet. Provided the fertilisers were applied in the normal way in spring, ploughing-in straw during the previous autumn gave 11 cwt. per acre more potatoes. Where half the fertilisers were applied in the autumn with the straw there was no such benefit from straw. These results suggest that the benefit from ploughing-in straw is mainly physical. For potatoes, but not for sugar beet and barley, this improvement more than makes up for the inevitable loss of immediately available nitrogen as the straw decomposes, provided that the nitrogen fertiliser for the potatoes is held over until spring. Straw compost gave much lower yields than fertilisers alone for all three crops.

The residual effects on the second crop after application were somewhat different from the immediate effects. Straw ploughed-in had negligible residual effects on sugar beet and barley but had marked residual effects on potatoes, both series of plots with straw ploughed-in giving 20 cwt. per acre more potatoes than plots without organic manures. The plots with residues from straw compost gave lower yields of sugar beet and barley but higher yields of potatoes than those without organic manures.

The results as a whole show that ploughing-in straw improves the physical properties of this heavy soil and gives better yields of potatoes. The straw locks up available nitrogen and it is necessary to give additional nitrogen fertiliser to the following crops. This extra nitrogen should be given at the normal time for the crop and not applied with the straw. Composting straw locks up available nitrogen and composts should not therefore be regarded as effective substitutes for inorganic nitrogen.

From 1934 to 1937 the experiment also included tests on the effects of autumn-sown rye and vetches or catch crops. Rye between barley and sugar beet averaged only 3·4 tons green stuff per acre and the rye between the other crops were much smaller. The vetch crops were very small. The rye reduced the yields of the following crops, the reduction being largest for barley grain and straw and sugar beet tops. The rye, like the straw, reduced the amount of nitrogen available to the following crops. The small crops of vetches had negligible effects apart from a small reduction in the potato crop.

In 1942 the sugar beet crop showed symptoms of magnesium deficiency, which was confirmed by leaf analysis. Magnesium sulphate at 2·5 cwt. per acre was added to some of the sugar beet crops in each subsequent year but there were no effects on yields and the symptoms of the deficiency were not observed again.

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THE FARMS

By J. R. MOFFATT

Rothamsted

The management of the Rothamsted and Woburn Farms was merged in October, 1946, and this necessitated a reorganisation of the administrative staff. Mr. C. R. L. Scowen was appointed in October, 1946, to assist with the management of the Rothamsted Farm, while Mr. G. F. Cole relinquished some of these duties to assist with the general management and supervision of field experimental work at the Woburn Farm. The field staff, led by the farm foreman, numbered about 20, and included 4 German prisoners of war who were billeted on the farm. It was only through the splendid efforts of the staff, working as a team, that the effects of the year's very adverse weather conditions were not more serious. Most of the field operations needing much hand labour were done by German prisoners working under contract, as this proved the only satisfactory method of engaging gangs. Potato planting and picking, and the singling, side-hoeing and harvesting of the mangolds and sugar beet were all carried out in this manner.

In 1947 the area of land farmed at Rothamsted totalled 503¾ acres, of which 345¾ acres were under tillage. The area of permanent grassland was 127½ acres, of which 62 acres were under long-term experiments, 26 acres were rented grazing, and the remainder mostly unploughable ground because of the presence of tree-stumps, etc. Of the arable crops, barley occupied the biggest area (90¾), followed by wheat (60½), and potatoes (30¾). Other crops included oats, linseed, beans, kale, mangolds, sugar beet and rye. The area under temporary leys was 98¼ acres.

Compared with 1946 these figures show a slight increase in the tillage area, with a corresponding decrease in the permanent grass. The area under the various crops remained much the same as in previous years, except that barley increased by 20 acres, and 19 acres were under linseed, which crop was not grown in 1946. In the late spring of the year 19½ acres of old grassland were ploughed up, and as the wireworm infestation, as shown by counts made on soil samples, was heavy, linseed and kale were the first crops taken, these crops being more resistant to damage by this pest than most other crops.

The number of experimental field plots laid out during the year numbered 1,479, rather less than usual. However, the increasing complexity of the experiments and the extremely unfavourable weather conditions in autumn and spring made it impossible to handle successfully any more plots. A detailed description of the field experiments carried out is given in the report prepared by the Field Plots Committee.

The predominant factor governing field work in any year is the weather, and in the season under review conditions were almost as unfavourable as they could be. All extremes of weather were encountered; the winter was the severest in living memory, and this was followed by a very dry, hot spell lasting throughout most of the summer and autumn. Rainfall varied from 5·74 in. in November, 1946, to 0·10 in. in October, 1947. The total rainfall for 1947 was

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only 22·08 in., almost 6½ in. below the average, while even after the long, hot summer the total hours of sunshine were 12 below average. Despite the long, cold winter, however, and a mean temperature in February of 11·4° F. below the average, the mean temperature for the year was 10° F. above the average, each one of the last nine months being warmer than usual.

The late harvest of 1946 and the large acreage of potatoes grown delayed the start of winter corn sowing. The very wet weather in November, 1946, when there were 23 wet days, with a rainfall of well over twice the average, considerably hampered this work. Little more than half the scheduled wheat acreage was sown, and part of the area not sown to wheat was sown to barley in the spring.

Frosts were almost continuous from December, 1946, to mid-March, 1947, and the thermometer did not rise above freezing point at all between the 11th and 25th February. On 24th February the screen temperature fell to 4·4° F., 27·6° of frost. Snow which fell in January was added to in February and March, and did not start to melt until mid-March. With the thaw came floods, and the lowest parts of most of the fields were under water for several days. A gale followed, with gusts up to 60 m.p.h., which stripped the roof from the feeding stuffs loft and blew in a large part of the brick gable end of the building. Trees were brought down, and many stacks were disturbed.

Throughout this period no land work at all was possible; and in the 5 months ending 31st March land work was possible on only 30 days. However, the farm staff were gainfully employed, mostly under cover, during the whole of this period, either sorting potatoes stored in large heaps under the Dutch barns or threshing the 1946 corn crops stored in outside stacks and in the barns. The average yields per acre for 1946 over the whole farm were:—wheat, 28·13 cwt.; barley, 20·9 cwt.; oats, 21·3 cwt.; and beans, 18 cwt.

The damage resulting from this severe winter, though serious, was not as devastating as was at one time feared. Most of the winter wheat survived, although the plant was thinned and patching was needed on some areas. No winter oats or barley had been sown. The winter beans, which were sown very late in the autumn, were severely damaged, and there were not sufficient plants left to warrant leaving the crop. Most of the leaves and stems of clovers were killed, but the crowns survived and the plants were able to re-establish themselves. Part of the kale crop which had not been consumed was destroyed, and the mangolds in an outside clamp were damaged.

Land work in spring could not start until early April, about 5–6 weeks later than usual, and throughout the season each operation was, as never before, a race against time. However, the handicap at the start was so great that none of the spring sowing operations could be done on time. Fortunately a spell of fine weather followed, and by working all the hours of daylight, 7 days a week, the spring cereals, sainfoin, and grass and clover seeds were sown by 20th April. The preparation of the ground for root crops followed, without interruption, as May was drier than usual, but a spell of very hot weather in the middle of the month, and another at the end, caused the surface of the ground to dry out, and considerably delayed the germination of these late-sown crops.

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By early June the field work was up to schedule. The winter wheat then looked rather disappointing, as it appeared to have thinned out considerably, despite top-dressings of nitrogenous fertiliser; the spring corn and linseed looked very satisfactory; the kale had escaped serious damage by fleabeetle and that grown after old grassland heavily infested with wireworm did not appear to suffer damage by this pest; the sugar beet, although rather irregular, was making headway; the mangolds had germinated unevenly and looked very backward ; many of the potatoes were not yet through the ground.

The thinness of the wheat crops enabled the weeds to grow rather more freely than usual, and to control them most of the wheat areas, and some of the barley, were sprayed with a salt of D.N.O.C., or dusted with a proprietary weed killing powder, with satisfactory results. One area of old grassland (Great Knott 1), which had not been ploughed since 1928, and which was ploughed up in late March and sown to kale, was heavily infested with Fat Hen (*Chenopodium album*) and yellow charlock. It seems likely that the seeds of these weeds have remained viable for nearly 20 years, merely awaiting suitable conditions for germination. Wild oats (*Avena* spp.), which originated in the continuous corn growing experiments in Broadbalk and Hoosfield, where they have assumed serious proportions, seem to be spreading over most of the farm. It is hoped to keep this weed under control, however, by reducing the number of corn crops grown in succession on any one area.

The growth of the hay crop was slow after a late start, and only a light crop was made in June. However, it was secured in excellent condition. In July the rainfall was almost an inch below average, and this proved to be the start of a very dry spell which lasted until early December. In each of the months July–November, 1947, the rainfall was well below the average, and the total for this period was only 4·46 in. compared with the average of 13·39 in., i.e., only one-third of the average. October, usually the wettest month of the year, yielded only 0·10 in.

The dry weather caused a rapid ripening of the corn crops and enabled the harvest to be gathered in in record time, the operation being completed by the end of August, which month had 271 hours of sunshine, 86 hours above the average, with a mean temperature 9·4° F. above the average. None of the corn was lodged, and most of it was carted without stooking and was stacked in the Dutch barns, while the remainder was threshed in the field. Threshing is not yet completed, so yields are not available; wheat yields will probably be considerably below, and barley and oats a little below normal. The main area of linseed produced a heavy crop, and the estimated yield is at least 12 cwt. per acre. As no seed of the variety "Royal" was available the variety "Bison" was sown, along with a little American seed. The heavy crop was cut with a binder and proved a slow and tedious job. The sheaves were turned after lying for three days, and carting followed two days later. A smaller area of "Redwing" was grown in a field where wheat had failed owing to severe wireworm damage. This crop was sown rather late, and was affected by the drought. The estimated yield from this area is 7 cwt. per acre.

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Normally, potato lifting closely follows harvest, but this year there was a considerable interval as corn harvest finished early, while owing to the late planting and dry season the tops of the potatoes remained very green until mid-October. There was no late blight this year, and as the weather conditions were unfavourable to the disease no preventative routine spraying was done. The start of lifting was delayed to give the crop a chance to put on more weight. The experimental plots were lifted at the end of September, but the main area of non-experimental potatoes was not lifted until the latter half of October. Even then the tops were green and vigorous, and had to be burnt off with acid before lifting could commence. Yields were lower than usual, and the tubers smaller, but considering the lateness of planting and very dry season the estimated yield of 7–8 tons per acre must be considered satisfactory. The ground was very hard and dry, and resisted the penetration of the lifter blade, which resulted in more damage than usual to tubers. Most of them were stored in large heaps within straw bale walls to a depth of 12 ft. under the Dutch barns. In order to get the sacks in which the potatoes were carted from the field up to this height a sack-elevator was used very successfully, resulting in a big reduction in strenuous manual labour.

The lifting of the mangolds followed, but this crop was very disappointing, having suffered severely from the effects of late sowing and drought. The roots were generally very small and yields low. The crop was lifted by the end of October and was carted and clamped under good conditions.

The lifting of the sugar beet crop presented great difficulty, as the ground was so hard that it was extremely difficult to keep the beet lifting plough in the ground. This resulted in the ends of a large number of roots being broken off. The roots were easier to clean than ever before, however, and the whole operation was completed by mid-November, about three weeks earlier than usual. Yields were well below average, but this was mitigated to a certain extent by the very high sugar content. The main beet experiment gave an average yield of 8·75 tons per acre of clean beet, with an average sugar content of 20·53 per cent., a sugar yield of 36·3 cwt. per acre.

Autumn ploughing was seriously impeded by the hard state of the ground and the shortage of plough-shares. Some of the fields were in fact too hard to plough at all, and those which were ploughed turned up very hard and dry, and needed a lot of working to get a suitable seed bed. Because of these hard, dry conditions the drilling of winter corn and beans was delayed, but as the drought remained unbroken by the end of the third week in October seed beds were forced by the use of cultivators and rollers. By the end of the month, with the drought still unbroken, most of the winter corn and beans were sown. Certain areas were still too hard to plough, and the cropping schedule had to be revised accordingly. Approximately 90 acres of winter wheat were drilled, the main varieties being Bersee and Squareheads Master 13/4. The winter bean area was destroyed by birds where the seed was drilled, but where the seed was dropped into the furrow bottom during ploughing little damage has been done. In future, beans will be either placed

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in the furrow bottom or will be broadcast on the surface of the ground before ploughing and then ploughed in. In the past, both these methods have given satisfactory results.

Only a few small areas were undersown with grass and clover seeds during the year, and most of these survived the drought. The area undersown with sainfoin had to be ploughed up as the plant was too thin to warrant leaving it.

Rainfall during December was heavier than usual, but it was not until the middle of the month that the rain reached ploughing depth. Conditions for ploughing were then excellent, and most of the winter ploughing was finished by the end of the year.

The season was an extremely unfavourable one for livestock. Fortunately the cattle survived the hard winter without losses or serious setbacks, although they made heavy inroads into the stocks of hay. A bunch of Irish bullocks was purchased in the autumn of 1946, and most of these were out-wintered with the intention of selling them fat off the grass during the summer of 1947. However, as a result of the hard winter they were in rather poor condition by the spring, and just as they were beginning to thrive really well the drought caused a severe shortage of grass. This resulted in only a few of the cattle being fattened from the grass, and to get these away they had to be fed liberally with kale and concentrated feeding stuffs. Several of the more forward beasts were brought into the covered yards in the autumn of 1947 to fatten by Christmas. The less forward beasts lived during September, October and November mainly on barley straw, helping themselves from stacks built in the grass field from the 1946 and 1947 crops. They maintained their condition on this diet but will have to be over-wintered again before being fattened off during the summer of 1948. The position was aggravated during the summer as owing to the very severe effects of the drought on grass on the light Woburn soil some of their cattle had to be transferred to Rothamsted. During the summer the Blue-grey and Kerry cows, which had been kept to rear stock of known history for grazing experiments, were sold. Most of them were about twelve years old and fetched more than their original price. No new breeding policy has yet been formulated as this will depend to some extent upon the programme of field experiments now under consideration. Most of the calves reared by these cows during 1945 and 1946 are still on the farm, and will be used for the last season of the grazing experiment comparing the residual value of feeding stuffs with the conventional estimates of their manurial value applied as fertilisers.

Sheep, too, survived the hard winter without loss and appeared to maintain their condition. Fortunately, lambing did not commence until the weather improved, and the 100 Halfbred ewes reared 163 lambs. The shortage of grass considerably reduced the milk yield of the ewes and consequently the lambs did not do as well as was expected. Weaning was delayed for this reason, and owing to the absence of fresh grass for the lambs they were almost immediately folded on to the kale. Most of them were sold fat by the end of the year. About 30 of the most forward ewe lambs of the 1947 crop were tupped in the autumn of 1947 by a Suffolk ram, and about 30 of the cross-bred ewe tegs of the 1946 crop were

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retained for the breeding flock. Several of the old ewes which would normally have been culled were also retained in the flock for another year, and a few of the best ewes from Woburn were transferred to Rothamsted. The rams used for the production of fat lambs were Oxfords and Suffolks.

The use of purchased feeding stuffs for livestock was almost eliminated, the only exceptions being the sugar beet pulp allotted to us as growers and certain feeding stuffs required for the animals on experiments. The protein-rich food in the home-produced rations consisted almost entirely of beans.

During the period between the end of harvest and potato lifting general estate maintenance work, including hedge trimming and the removal of barbed wire from around the Manor House, was undertaken. This work was continued after beet-lifting had finished, and all hedges were finished, but a lot of work remains to be done before the grounds of Rothamsted House attain their pre-war condition.

Work was commenced on the much needed new road between the farm and laboratories, and six new cottages for farm workers are in course of erection. No additions to the farm buildings were made, although new office accommodation was provided by the conversion of buildings previously used for other purposes.

The farm was worked, as in the past few years, by 4 wheeled tractors and 2 teams of horses, the latter used mainly on the experimental plots and for carting. Little new equipment was purchased, other than the sack elevator and a small rotary hoe for keeping clean the paths in the experiments.

The year under review was an extremely difficult one from the farming point of view. A wet autumn followed by the severest winter in memory caused all operations to be rushed in a vain attempt to make up for the late start. It was disappointing that the results of the tremendous efforts made in the spring were not fully realised because of the severe drought which lasted throughout the summer and autumn. This greatly restricted the growth of all crops and resulted in yields which were generally well below our average. The dry conditions also hampered the preparation of the ground for the 1948 crops, but it is hoped that more normal weather will prevail in 1948 so that crop yields will be a truer reflection of the work involved.

Woburn

On 1st October, 1946, the management of the Woburn Experimental Farm was merged with that of the Rothamsted Farm, and this report covers the first year's work.

Prior to 1947 considerable emphasis had been laid on market garden crops which, with sugar beet and some potatoes and barley, formed the main arable crops. There was also a considerable area of poor quality grassland but the only stock kept was a very small pig herd and a small sheep flock kept primarily for experimental work on Swayback disease in lambs. The market garden crops demanded more labour than seemed justified on an experimental farm, and the time taken in the marketing of the small amount of produce seemed out of proportion to the returns. It was therefore decided to abandon the growing of non-experimental market garden crops.

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The main objectives in the first year were:—

1. To retain the existing experimental field programme and to prepare other potential sites for field experiments.
2. To clean the arable land of twitch and other arable land weeds by increasing the area under cleaning crops such as potatoes, or, where necessary, by fallowing.
3. To increase the productivity of the arable land by better and more timely operations, by the increased use of fertilisers, especially nitrogenous fertilisers, and by the employment of seasonal labour when required.
4. To reduce the area of grassland by ploughing up the least productive grass, and to increase the productivity of the remaining grassland by increased stocking and proper management, and the judicious use of fertilisers.
5. To provide such new implements and machinery as were required to replace worn out equipment.

However, the year proved a very difficult and disappointing one, due very largely to the wide extremes of weather which prevailed. This factor severely hampered the execution of the work planned, and throughout the whole year each farming operation was, as never before, a race against time and many of the results have been disappointing.

Of the 128¾ acres farmed in 1947, 42 acres were under cereal crops, 13½ acres under potatoes, and 6½ acres under sugar beet. Grassland occupied 45 acres, 16 acres were bare fallowed and 5¾ acres were under sundry experimental crops. The number of experimental field plots was restricted to 330, though as on some areas two crops were taken the total number of plots harvested was 450. A more detailed report on the individual experiments will be found in the report of the Woburn Station.

The season started off well with a fine and dry October, which enabled the small potato crop to be gathered under excellent conditions and the autumn ploughing to make good progress. Unfortunately the weather then broke and in the months of November and December the rainfall totalled almost 7 in. compared with the average of 4·6 in. The harvesting of the sugar beet crop was seriously delayed and was not finished until early in January, 1947, and only a small proportion of the area scheduled for winter corn could be sown.

There followed a spell of unprecedently hard weather with almost continuous hard frosts and heavy falls of snow. On two nights in February the minimum temperature fell to minus 4° F and minus 5° F., and the mean for the month was 22·3° F. compared with a normal mean of 33·0° F. The snow did not melt until the end of March, and gave a rainfall figure of 4·72 in. for the month compared with the average of 1·76 in. No land work at all was possible from early January until the end of March, and this put the spring programme of work very seriously behind schedule. Many of the plans for thorough cleaning operations before spring sowings had to be abandoned, and all field operations had to be hurried through to make up for lost time. The small areas of winter wheat, rye and barley survived without damage.

Fortunately the months of April and May were generally favourable to land work, but though operations were pushed ahead

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as rapidly as possible all crops were sown late. In April 8½ acres of grassland were ploughed up and sown to barley almost immediately. Potatoes were the last crop to be planted and this operation coincided with a spell of very hot weather which dried out the ground very rapidly.

The rainfall in May was only about half the normal, and this proved to be the start of a severe drought which persisted for almost 7 months. In each of the 7 months May to November, 1947, the rainfall was below normal, while the total for the period was only 6·23 in. compared with the average of 15·42 in. This lack of rain combined with temperatures well above the normal severely restricted the growth of crops. Corn crops were least severely affected and most of them looked satisfactory; the only exception was an area of Bersee wheat sown late in spring, which, despite very heavy top dressings of nitrogen made only very slow growth. Growth of sugar beet and potatoes were obviously retarded; the sugar beet wilted considerably during the long hot days; the potatoes, especially the late planted ones, were slow in coming through and then only grew slowly; grass made very little growth and by the end of July was completely burnt up, the grassland appearing not unlike stubble fields. The one hay field gave only a very low yield despite a top dressing of 3 cwt. of sulphate of ammonia, and all the undersown seeds were burnt up just after harvest. The effect of the drought on the individual experimental areas is described in the report of the Woburn Station.

The weather was ideal for operations on the fallow ground for the eradication of twitch. Three areas in Stackyard field were fallowed; the permanent wheat plots to eradicate creeping soft grass (*Holcus mollis*), the permanent barley plots to eradicate creeping soft grass and Fiorin (*Agrostis stolonifera*), and series C, not at present under experiment, to eradicate Fiorin. Wild Oats (*Avena* spp.) were also prevalent in the permanent barley plots, with some on the wheat plots, but it is unlikely that the fallowing did much to reduce the number of seeds of this weed as the ground was too dry for germination.

Conditions for harvesting were ideal and all crops were carted with a minimum of labour, many of them without having been shocked. The Rothamsted harvesting technique was used for the first time on the experimental plots, and threshing was done soon after harvest with a small portable machine from Rothamsted. The overall average yield of barley was just over 18 cwt. per acre, and of wheat (including the disappointing area of spring wheat) just over 14 cwt. per acre.

Potato lifting was delayed until towards the end of October as the tops remained green and the tubers appeared to be still growing. The tops were burnt off with sulphuric acid to facilitate the lifting, while the picking was done by German P.O.W. labour. The crop was cleared under excellent conditions, and the estimated yield of 6 tons per acre, though low, must be considered reasonable for the season. The crop was stored under cover so that sorting would provide a wet weather job during the winter months.

Sugar beet lifting followed and was done by the regular staff. The roots were very small but the sugar content, especially of the

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beet lifted first, was high. Yields were approximately 6 tons per acre of clean beet with an average sugar content of 18·9 per cent.

The early completion of harvest should have provided the opportunity for thorough cleaning operations in the autumn, but the ground proved to be much too hard for this work. The ploughing of stubbles had to be abandoned for the same reason, and though the ground gradually became softer some of the fields could not be ploughed satisfactorily until late November. On some of the land which might have been ploughed earlier the work was held up by the scarcity of plough-shares. The difficulty in preparing the land prevented the sowing of autumn wheat on most of the area scheduled for this crop.

Livestock

Twenty-one Irish crossbred cattle were purchased in the autumn of 1946 to graze down the understocked grass and to make farmyard manure in covered yards during the winter. It was hoped that the beasts would fatten on the grass during 1947. However, the grass made such little growth that there was no hope of fattening these beasts and ten of them were transferred to Rothamsted in June. The remaining eleven had insufficient grass on which to fatten, so they have had to be yarded again as stores for the winter of 1947–48 as there is insufficient hay and feeding stuffs on which to fatten them in the yards.

The ewe flock, which consisted mainly of very old ewes of very mixed breeds and crosses, suffered severe casualties during the year; 20 of them died, mainly through old age. Those that survived produced a small crop of weakly lambs which have not done at all well. There were only about 6 ewes worth retaining, and these were transferred to the Rothamsted flock. The remainder of the old ewes were transferred to Rothamsted for fattening off on kale, and after the 1947 lamb crop has been disposed of the land at Woburn will be rested from sheep for one or two years.

The pig herd, which had been maintained at 5 breeding sows during the war years, has been increased rapidly by retaining some of the best of the home bred gilts and by the purchase of small gilts from other herds. Most of the young pigs reared have been sold locally for fattening, many of them to members of a local pig club.

Implements

During the year considerable progress has been made in re-equipping the farm with modern implements to replace old and unreliable ones.

Summary

The year 1946–47 has been a very difficult one, with many disappointments and much frustration, due almost entirely to wide extremes of weather conditions. The time lost in the late autumn, winter and early spring was never regained, while the severe drought considerably reduced growth of all crops and so affected yields considerably. Although it was not possible to execute much of the work which was planned, considerable improvements have been made during the year, and plans are prepared for a considerable expansion of output in 1948.

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WOBURN EXPERIMENTAL STATION

By H. H. Mann

The general design and the principal results of the long-term experiments at Woburn were outlined in the Report for 1946 and are not repeated here.

The Station is on a light sandy soil, very deficient in lime and over a great depth of sand derived from the Lower Greensand. These conditions provide a great contrast with those at Rothamsted. The whole of the farming operations are much more influenced by weather conditions, especially by long and persistent droughts. On such a soil the conditions of 1947 were particularly trying. The winter precipitation was heavy for all months with 4·75 in. in November, 1946, and 4·89 in. in March, 1947. Frost and snow delayed the commencement of spring work, and there ensued a summer of almost unprecedented dryness, the rainfall from April to October being only 6·61 in. against a normal of 14·63 in. This did not seriously affect the yields of crops which had become well established before the long dry spell set in, but the effect on crops sown later or transplanted was disastrous; the yield of grass in the later part of the season was very small indeed.

A. Field experiments

1. *Continuous wheat and barley experiments*

The area which has been devoted to continuous wheat and barley growing since 1877 had become, for the third time since the experiment was started, so very weedy in 1946 that it was resolved to fallow the whole area, with frequent cultivations. So far as the wheat area is concerned the chief weeds have been the two grasses, both well known "twitches", *Holcus mollis* and a variety of *Agrostis* (probably *A. gigantea* var. *dispar*). These two grasses, which first became serious on the plots where, owing to acidity, wheat would no longer grow, gradually overspread the whole wheat area. With the usual amount of cultivation the *Agrostis* was gaining ground on the *Holcus*, but when an extra amount of autumn cultivation was given (as in 1945) the former almost disappeared while the *Holcus* was more in evidence than ever in the following year. It remains to be seen what relative effect the very intense cleaning of the land during the whole of the year 1947 has had on the two grasses, and observations on this point will be made during 1948.

The weed herbage of the continuous barley area was of a different character. Here, though the "twitches" were present, *Holcus mollis* was only found in small amount, and *Agrostis* was much less abundant than on the wheat area. On the other hand, wild oats, which were a comparatively unimportant pest till 1943, had increased so much in 1945 and 1946 that the crop of barley was very largely stifled. The phenomenon of the sudden rise of this weed to the position of a serious menace has been noticed in many parts of the country.

2. *Maintenance of fertility of light land*

One of the purposes of the Woburn Station is to determine the best method for the maintenance of the fertility of light land.

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Several long-term experiments have been in progress for a number of years on problems of special importance at the present time when the amount of farmyard manure available is becoming less and less. Reports on these experiments for 1947 are given below.

(a) *Alternate husbandry experiment.* Four rotations are compared:—

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

and their effects on soil fertility are tested by the yields of potatoes followed by barley. The results in 1947 were generally similar to those in the preceding six test seasons, though the potato crop was small. The yields of potatoes after grazed ley or hayed lucerne were higher than after the arable rotations. The response of the potatoes to farmyard manure was less after grazed ley than after the other rotations.

(b) *Six-course rotation experiment on inorganic fertilisers.* The 1947 crops were the eighteenth in this experiment, which tests the effects of increasing amounts of N, P and K fertilisers on a rotation of barley, clover, wheat, potatoes, rye and sugar beet.

In 1947 there were clear responses to sulphate of ammonia applied on 17th April to barley, wheat and rye before the drought began to be serious but there was little or no response when the sulphate of ammonia was applied later to sugar beet (1st May) and potatoes (12th May).

(c) *Green-manuring experiment.* This experiment was laid out in 1936 and re-designed in 1945 to test the effects of ryegrass, clover (both undersown in the previous crop of barley), rape, lupins and fallow as preparations for cabbages transplanted in July and followed by barley. The results in 1947 were unusual. Plots which had carried good crops in the first half of the season were very dry when the cabbages were transplanted. The best cabbages were on the plots which had a bare fallow, and the worst on those where a large amount of clover or ryegrass was ploughed in shortly before the cabbages were transplanted. The barley crop showed similar results for the organic matter ploughed in during the summer of 1946. In the exceptional 1947 season the crops were smallest where most organic matter had been ploughed in.

(d) *The making of a market garden soil.* This experiment was started in 1942 to determine the relative value of farmyard manure, vegetable compost, sewage sludge and a compost made from sewage sludge and straw on a two-year rotation, viz., green peas and leeks, globe beetroot and winter cabbages. The year 1947 was a particularly difficult one for this experiment. The globe beetroot crop was late and the winter cabbage crop which followed it failed. The leek crop had to be watered twice to save it. The globe beetroot gave poor results with sewage sludge alone or in compost, but the green peas and leeks behaved similarly with all the organic manures. Crops, especially green peas, on plots without organic manures showed much greater effects of the drought.

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3. *Other field experiments*

For a number of years the Woburn farm has taken a share in the study of certain exotic crops which it was thought might be suitable for cultivation in this country. Three of these crops have again been grown in 1947, namely soya beans, an early ripening maize, and two varieties of sweet lupins. The year under report was favourable to all these crops. All seemed to have less difficulty than our local crops in establishing themselves under conditions when the soil was rapidly drying up, and the high temperatures which followed proved very favourable to the ripening of crops which do not mature easily in England.

The Manalta maize, which we originally got from Canada, sown on 5th May, ripened well and was reaped on 15th September, almost a record for this country, and gave a good crop. Several types of maize received from Canada, however, reputed to ripen in 95 days, but planted on 13th June, failed to ripen at all. The times of ripening given in the literature for varieties have evidently no meaning for this country with its much cooler summer than the areas where maize is usually grown.

The experiments with sweet lupins have led to two results. The first is that the amount of fodder that can be obtained from a yellow sweet lupin crop on the very suitable soil of Woburn was 14½ tons of green material per acre. This was grown between 22nd May and 21st August, or in 91 days. Though classed as a sweet lupin it was still somewhat bitter and sheep did not take to it readily, but ultimately ate at least all the leafy parts. The second point refers to the very great attractiveness of sweet lupins to rabbits, and the sweetest of the lupin varieties was eaten out completely in the area which was not specially protected.

B. POT EXPERIMENTS

1. *Clover sickness*

Results of earlier work have been confirmed and, in addition, it was found that although fertilisers alone make very little difference to clover sickness, fertilisers combined with lime have a distinctly beneficial effect. On the other hand increasing the acidity of the soil at least to a pH value of 5·4 does not cause the soil to show symptoms of clover sickness.

In experiments on soil temperatures, partial waterlogging and the proportion of clover to soil, it was found that soil kept at 30° for a whole season showed more signs of clover sickness than any of the other treatments.

2. *Competition of crop plants and certain weeds*

Results on the competition of barley and *Agrostic* twitch were closely parallel to those already described with *Holcus mollis*.

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

In 1946, for the first time a healthy crop of barley had been grown in a soil at pH 4·3 after adding a large amount of soluble phosphate and a little calcium nitrate to the soil. In 1947 this was repeated without the addition of calcium nitrate and large plants were obtained, though with very little grain. Other crops reacted differently. Lucerne gave an abundant crop with soluble phosphate

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alone though the plants hardly grew on the untreated acid soil. With mustard the effect of phosphate was much smaller and with carrots it was very small.

C. LABORATORY WORK

An investigation has been commenced on the sulphur present in various forms in soil samples taken at various intervals since 1876 from the Permanent Barley plots.

D. STAFF

The Woburn Experimental Station has been under the charge o Dr. H. H. Mann during the whole period under report, while the farm has been under the management of Mr. J. R. Moffatt, who has directed the work from Rothamsted. Mr. T. W. Barnes has been chemist to the Station since 1929 and has remained in charge of the laboratory during the present year.

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