ROTHAMSTED RESEARCH

Report for 1937

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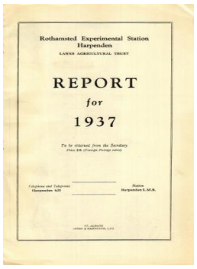

Work of the Department of Plant Pathology, 1918-1937

Rothamsted Research

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roots. There is no doubt that roots exert a stimulating effect on bacterial growth. Thus when nodule bacteria were placed in sand without any plants, their numbers after a fortnight rose from 1 to 3 millions per gram of sand, but in sand in which peas were growing, the numbers of bacteria rose in the same time from 1 to 6.1 millions. It is also known that the number of other soil bacteria is much increased by the near presence of plant roots. This large population of micro-organisms amongst the roots must be of great importance in affecting crop growth, and yet it affords an almost untouched field of investigation.

The development in this department of a method for estimating the total numbers of bacteria in soil now makes it possible to investigate the interaction of plant roots with soil bacteria, and it is proposed to undertake this when better laboratory accommodation is available.

There is some evidence that the important problem of clover sickness is related to this growth of micro-organisms upon or near the plant's roots. The fact that clover so often fails when grown too often on the same ground is sometimes attributed to definite fungal or eelworm infections, but there are instances which cannot be attributed to these causes and in which the commencement of the symptoms occurs so early as to exclude the factor of nodule formation by " parasitic " strains. A case at Woburn has been under investigation in collaboration with Dr. Mann. A sterile extract of clover-sick soil from this source has been found so toxic that, in its presence, clover seed is prevented from germinating or killed immediately after germination. It would seem that bacteria growing upon the roots of the preceding clover crop have produced some persistent toxic substance. The nature of this substance and the conditions which make for its formation offer a promising line of investigation which it is proposed to follow up.

But bacteria growing in the proximity of roots also produce effects beneficial to the plant. Thus it has been shown in our earlier work that the growth of root hairs is stimulated by the secretions of nodule bacteria living outside legume roots. This production of growth-promoting substances by soil bacteria may well be of great agricultural importance.

THE WORK OF THE PLANT PATHOLOGY DEPARTMENT AT ROTHAMSTED, 1918-1937

By J. Henderson Smith

The Mycology Department was instituted in 1918, and Dr. W. B. Brierley put in charge, with Miss Jewson as Assistant. At first it was housed in a single room of the old building, but in 1924 moved to the less cramped quarters in the new laboratory which it now occupies. The change gave scope for an increase in the staff, and in 1929 three additional members were added on the formation of the Virus Section. In 1932 Dr. Brierley left to take up the Chair of Agricultural Botany at Reading University ; and a few months later Dr. R. H. Stoughton who had joined the staff as bacteriologist was appointed Professor of Horticulture, also at Reading. On

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Dr. Brierley's leaving, the Department was reconstituted as a Department of Plant Pathology with Dr. Henderson Smith as Head. Stoughton who had taken over the duties of mycologist was succeeded by Mr. G. Samuel, who left in 1937 on being appointed Chief Mycologist to the Ministry of Agriculture ; and he was replaced by Mr. S. D. Garrett. In the Virus Section Dr. Caldwell left in 1935 to assume the post of Lecturer in Botany in the South-Western College, Exeter, and his place was filled by Mr. F. C. Bawdén.

The Department has always limited its activities almost entirely to the infectious plant diseases and concerned itself little with other forms, e.g. deficiency diseases. The infectious diseases fall under three main headings, bacterial, fungal and virus, and these are considered separately.

A. Mycology

During his fourteen years' service at Rothamsted Dr. Brierley devoted much attention to the genetical analysis of the fungus Botrytis, and isolated a large number of races. He found that new strains might arise, but they could not be produced at will by varying the conditions. A strain could be temporarily altered by changed conditions, but it returned to its old characteristics on reversion to the old conditions. Apparently pure natural infections often consist of a mixed population of various races but artificial inoculations give rise only to the original infecting race. Dr. Brierley's influence on mycology is not to be measured solely by his original published work : his knowledge and enthusiasm and wide acquaintance with leading mycologists throughout the world contributed largely to establishing the Department in the position which it now holds. Perhaps his most important single contribution was his paper " On a form of *Botrytis cinerea* with colourless sclerotia," (1920) in which is included a scholarly discussion on the significance of mutation in fungi.

In the early years of the Department, with its initially small staff, much time and energy was expended on the attempt to assess the numbers, as well as the kinds, of fungi in soils of different treatment, for which the classical fields of Rothamsted afforded unique material. No very satisfactory conclusions emerged from this work, largely because of the want of adequate methods of assessing numbers. The presence of long threads of mycelium, any fragment of which may give rise to a new colony and the enormous numbers of spores which a single head may produce presented difficulties which were not solved, and have indeed not been fully solved even yet. It was taken up again at a later date by J. Singh, who used the methods developed in the preceding work. He obtained no support for the view that particular manurial treatments produce specific fungus flora. There was a direct correlation between soil fertility as measured by crop growth (e.g. mangolds, wheat) and the number of fungi and actinomycetes in the soil ;

Brierley, W. B. (1920) " On a Form of *Botrytis Cinerea* with Colourless Sclerotia." Phil. Trans. Roy. Soc. Lond. B. 210 pp. 83-114.

Singh, Jagjiwan (1937). " Soil Fungi and Actinomycetes in Relation to Manurial Treatment, Season and Crop." Annals of Applied Biology. XXIV. 154-168.

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but he could obtain no conclusive evidence that the numbers in the soil showed a definite periodicity. That there is a correlation between manurial treatment and disease was shown for the potato by Kramer (1930) who found that phosphates reduced and nitrogen increased the liability to attack by *Corticium solani*. Excessive phosphate on the other hand increased the liability to pink rot, while there was no correlation between manurial treatment and blight.

Dr. Henderson Smith joined the staff in 1919, and began a series of studies on the killing of Botrytis spores by chemicals and heat, which are an important contribution to the general theory of disinfection. The types of the killing are different in the two cases. Whereas in heat-death the curve of the rate of destruction is the same at all temperatures, adjustment of the time scale giving identical curves, killing by phenol yielded a curve varying in shape from logarithmic to sigmoid according to the concentration of the phenol, the number of the spores and the age. This variation in type was satisfactorily explained on the assumptions that in any assemblage of spores the resistance of the individual varied, and the distribution of the grades of resistance was approximately normal; and a formula was arrived at, which expressed the relationship between time of exposure, number of spores, and rate of death. The effect of temperature on the velocity of the reaction by heat was unusually great but conformed to Arrhenius's law. It was pointed out that in all work of this type, e.g. in comparing growth rates, comparison of the times taken to reach a constant result gives more accurate and consistent results than the usual but misleading method of comparing the results reached in constant time.

Miss Muriel Bristol (now Mrs. Bristol Roach) was added to the staff to investigate the possibility that algae, especially green algae, play a significant part in soil fertility, and, using the then novel technique of pure algal cultures, she added much to our knowledge. The mode of life of these organisms differs according as they are on the surface exposed to light or below the surface in darkness. When they occur on the surface, they function like other green plants, transforming by photosynthesis inorganic material into organic material rich in potential energy which is added to the soil when they die. Below the surface they do not necessarily die, but can change their mode of life, becoming saprophytic on some of the organic matter already existing in the soil, as well as assimilating nitrate and phosphate, which they convert into insoluble but

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Smith, J. Henderson. 1921. "The Killing of Botrytis Spores by Phenol." Annals of Applied Biology. VIII, pp. 27-50.

Smith, J. Henderson. 1923. "The Killing of *Botrytis Cinerea* by Heat, with a Note on the Determination of Temperature Coefficients," *ibid*, X, 336-347.

Smith, J. Henderson. 1923. "On the Apical Growth of Fungus Hyphae." Annals of Botany, XXXVII, pp. 341-343.

Smith, J. Henderson. 1924. "On the Early Growth Rate of the Individual Fungus Hypha." New Phytologist. XXIII, pp. 65-78.

Kramer, L. 1930. Unpublished Ph.D. Thesis.

Roach, B. Muriel Bristol—"On the Relation of Certain Soil Algae to Some Soluble Carbon Compounds." Annals of Botany, 1926, CLVII, pp. 149-201, with 1 plate.

Roach, B. Muriel Bristol—"On the Carbon Nutrition of Some Algae Isolated from Soil." Annals of Botany, 1927, CLXIII, pp. 509-517.

Roach, B. Muriel Bristol—"On the Algae of Some Normal English Soils." Journ. of Agric. Sci., 1927, XVII, pp. 563-588.

Roach, B. Muriel Bristol—"On the Influence of Light and of Glucose on the Growth of a Soil Alga." Annals of Botany, 1928, CLXVI, pp. 317-345.

readily decomposible forms. They may therefore be regarded as agents which on the one hand increase the stock of energy material in the soil and on the other immobilise soluble nutrients and organic compounds which are available for later use.

At this time Sydney Dickinson was investigating the physiology and genetics of the smut fungi. For this purpose he devised an "isolator" for the isolation of single cells, which depended on a new principle and proved very satisfactory. He studied in detail the cytology of the covered smuts of both oats and barley and the fusion, both within and across the species examined, between the mycelia of different "gender" derived from single sporidial isolations. Incidentally he showed that no infection of oat or barley seedlings by pure cultures of smut fungi results if only one gender (sex) is present, but if two genders are present 90 per cent. infection is obtained.

With the appointment of Mr. Samuel a new orientation was given to the mycological work. Hitherto, it had been—apart from the work on wart disease of potato—somewhat abstract, and divorced from practical agriculture. The accumulated knowledge possessed at Rothamsted of soil conditions, however, seemed to offer an excellent opportunity for the study of crop diseases caused by soil organisms, and Mr. Samuel began with the club-root disease of crucifers. A new mycological glass-house was built in 1935 and the system of heating this and the existing virus houses was reconstituted, a thermostatically-controlled oil-burning plant being introduced to serve all the houses. Samuel worked first on the life-history of the organism producing club-root, and was able to clear up many points which had hitherto been obscure in this much-studied parasite. In the course of this work he devised a method for determining the amount of infection of the root hairs within a week of planting the seed. He showed that the extent of this root-hair infection was a fair index of the amount of disease, which would subsequently appear in the crop, and the method gave him a means of testing the effect of soil treatment in controlling the disease. He confirmed the belief in the value of lime-dressing, but showed that the effect was due not to the calcium content of the dressing but to the alkalinity produced, and that other alkalis, such as potassium or sodium hydroxide, were no less beneficial. This work, which is not yet published, was unfortunately interrupted by his departure to the Ministry of Agriculture; but he indicated a number of problems which should be attacked in any subsequent work on club-root.

Mr. Garrett, who had joined the staff in 1936, was appointed in 1937 to succeed Samuel as mycologist, and has continued in a different field the study of the effect of soil-conditions on disease. The Take-all disease of wheat, or whiteheads as it is also called

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Dickinson, Sydney—"Method of Isolating and Handling Individual Spores and Bacteria." Proc. Roy. Soc. Medicine, 1926, XIX, pp. 1-4. (Section of Pathology.)

Dickinson, Sydney—"Experiments on the Physiology and Genetics of the Smut Fungi: Hyphal Fusion." Proc. Roy. Soc. Lond., 1927, B, 101, pp. 126-136, with 1 plate.

Dickinson, Sydney—"Experiments on the Physiology and Genetics of the Smut Fungi: Seedling Infection." Proc. Roy. Soc. Lond., 1927, B., 102. pp. 174-176.

Dickinson, Sydney—"Experiments on the Physiology and Genetics of the Smut Fungi: Cultural Characters. The Effect of Certain External Conditions on their Segregation." Proc. Roy. Soc., Lond., 1931, B., 108. pp. 395-423.

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produced by *Ophiobolus graminis* had long been known as a serious disease in other parts of the world, but although present has not been of much significance here until the last few years. It is now becoming of considerable importance, and the reason for the change is not yet clear. It has coincided with the development of mechanised farming, but the connection, if any, has not been established. Garrett is studying the effect of various soil conditions such as moisture, temperature, organic matter content, on the survival period of the fungus, which he has already shown to depend very largely on the environmental conditions. Miss Glynne is studying the fungus *Cercosporella hispotrichoides*, which is in part responsible for " lodging " in wheat, and has during the last eight years maintained a survey of the diseases present in the Rothamsted and Woburn plots.

Wart Disease of Potatoes

The introduction by Miss Glynne (1925) of the " green-wart " method of infection was an important contribution to the study of this disease, since by it susceptibility or immunity could be determined within as many weeks as had hitherto required years. It is now in official use as a routine method and continues to give satisfactory results. It is, however, so sensitive a test that many varieties which were accepted as immune in the field were shown by it to be temporarily susceptible, and the question has arisen whether the laboratory or the field test should be accepted as the criterion of immunity, on which official recognition should be based. On the one hand the Ministry of Agriculture are reluctant to accept as immune varieties which are in the laboratory demonstrably susceptible for a time, lest this susceptibility should lose its temporary character under some conditions of growth or environment ; and on the other it seems unreasonable to reject many promising new varieties on account of susceptibility to an exposure much more severe than could reasonably be expected under field conditions. A final decision has not yet been reached on this matter.

By grafting immune and susceptible plants together W. A. Roach (1927) showed that the immunity is not due to a chemical compound which could traverse the plant and be conveyed from the immune into the susceptible grafts. (*See* Annual Report 1936, p. 85.) Miss Martin (1929) using the "green-wart " method demonstrated the susceptibility to wart disease of numerous species of Solanaceae other than the potato plant, though infection did not

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Glynne, Mary D.—" Incidence of Take-all on Wheat and Barley on Experimental Plots at Woburn." Annals of Applied Biology, 1935, XXII, pp. 225-235.

Glynne, Mary D.—" Some New British Records of Fungi on Wheat." Trans Brit. Mycolog. Soc. 1936, XX, pp. 120-122.

Glynne, Mary D.—" Infection Experiments with Wart Disease of Potatoes. *Synchytrium endobioticum* (Schilb) Perc." Annals of Applied Biology, 1925, XII, pp. 34-60.

Glynne, Mary D.—" The Viability of the Winter Sporangium of *Synchytrium endobioticum* (Schilb.) Perc." Annals of Applied Biology, 1926, XIII, pp. 19-36.

Glynne, Mary D.—" The Development of *Synchytrium endobioticum* (Schilb.) Perc., in Immune Varieties." Annals of Applied Biology, 1926, XIII, pp. 358-359, with 1 plate.

Roach, W. A.—" Immunity of Potato Varieties from Attack by the Wart Disease Fungus, *Synchytrium endobioticum*, the Fungus causing Wart Disease of Potatoes." Annals of Applied Biology, 1927, XIV, pp. 181-192.

Roach, W. A. and Glynne, Mary D.—" The Toxicity of Certain Sulphur Compounds to *Synchytrium endobioticum*, the Fungus causing Wart Disease of Potatoes." Annals of Applied Biology, 1928, XV, pp. 168-189.

Martin, Mary S.—" Additional Hosts of *Synchytrium endobioticum* (Schilb.) Perc." Annals of Applied Biology, 1929, XVI, pp. 422-429, with 2 plates.

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occur from contaminated soil. In spite of much investigation no field method was discovered for treating the soil so as to kill all sporangia of the organism. Treatment with sulphur proved effective on some occasions but not always. It would seem that it is not the sulphur itself which is active, but some derivative from it, and experiments by Miss Glynne and W. A. Roach (1928) suggested that thio-sulphuric acid has a special toxic action over and above that due to the hydrogen ion concentration, which in itself has a definite effect in suppressing the disease when sufficiently high.

For the last few years Miss Glynne has been acting as an official consultant examining all doubtful cases of susceptibility in collaboration with the testing station at Ormskirk and Edinburgh.

B. Bacteriology

In 1927 Mr. R. H. Stoughton began an extensive series of investigations into the "angular leaf spot type" of the Black Arm disease of cotton, the funds for which were provided by the Empire Marketing Board. One of the objects of this enquiry was to see how far the study of a tropical disease can be usefully carried on in a laboratory in England; and the findings were compared with those obtained in the Sudan. In the result it appears clearly that certain types of investigation can be adequately and more economically carried out in this country, and there are many incidental advantages in such co-operation between the tropical and British workers.

In our glasshouses cotton grew well, developing ripe bolls with good lint and healthy seed. The infection experiments were mainly carried out in specially designed chambers, in which the air and soil temperatures and the air moisture and light exposure could be controlled and varied at will within certain limits. The results of the six years' work on the influence of environmental conditions on the disease may be summarised as follows. Primary infection of the cotyledons is usually due to the bacteria (*B. malvacearum*) carried on the outside of the seed and in the fuzz, thorough disinfection of the exterior of the seed resulting in healthy seedlings. Soil temperature affects the amount of primary infection, which is reduced when the temperature is constant above 30° C., but not inhibited wholly at 40°, but is of importance only during the first two or three days after sowing. A regular diurnal variation produced the same effect on infection as a constant temperature near to the mean of the fluctuations. Soil temperature has little effect on secondary infection resulting from spray inoculation of the plants, but

Stoughton, R. H.—"The Morphology and Cytology of *Bacterium malvacearum*." E. F. S. Proc. Roy. Soc. Lond., 1929, B., 105, pp. 469-484, with 1 plate.

Stoughton, R. H.—"The Morphology and Cytology of *Bacterium malvacearum*." E. F. S. Proc. Roy. Soc. Lond., 1932, B. III, pp. 46-52 with 2 plates.

Stoughton, R. H.—"Apparatus for the Growing of Plants in a Controlled Environment." Annals of Applied Biology, 1930, XVII, pp. 90-106, with 2 plates.

Stoughton, R. H.—"The Influence of Environmental Conditions on the Development of the Angular Leaf-Spot Disease of Cotton." Annals of Applied Biology, 1928, XV, pp. 333-341.

Stoughton, R. H.—"II. The Influence of Soil Temperature on Primary and Secondary Infection of Seedlings." Annals of Applied Biology, 1930, XVII, pp. 493-503.

Stoughton, R. H.—"III. The Influence of Air Temperature on Infection." Annals of Applied Biology, 1931, XVIII, pp. 524-534, with 1 plate.

Stoughton, R. H.—"IV. The Influence of Atmospheric Humidity on Infection." Annals of Applied Biology, 1932, XIX, pp. 370-377.

Stoughton, R. H.—"V. The Influence of Alternating and Varying Conditions of Infection." Annals of Applied Biology, 1933, XX, pp. 590-611.

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the effect of air temperature is marked, maximum infection occurring at a constant temperature of 35°-38° C., with decreasing incidence at progressively lower temperature. High humidity favours infection, but humidity is of importance only during the first two days after inoculation.

Mr. Stoughton also completed an important study on the morphology and cytology of *B. malvacearum* in which he showed that this bacterium has apparently a sexual stage, though such a complexity is not supposed to occur in bacteria; and that it may dissociate suddenly into new strains which may or may not persist.

C. Virus Disease

The Imperial Agricultural Conference of 1927 recommended that "funds should be provided for the more extended study of the fundamental nature of virus diseases in plants," and the Empire Marketing Board provided means for a considerable development of the virus investigations already being carried out at Rothamsted by Dr. Henderson Smith. Three scientific posts were created, Dr. John Caldwell being appointed in 1929 as Virus Physiologist, Dr. Frances Sheffield as Virus Cytologist and Miss Marion Hamilton (now Mrs. M. A. Watson) as Virus Entomologist. A glass-house for general purposes had already been built in 1927, and a second insect-proofed set of chambers was provided in 1929 for the virus investigations. These were designed to elucidate if possible the ultimate nature of viruses in general and were not concerned with particular diseases of particular crops, for the study of which provision was made in different stations scattered in suitable localities throughout the country.

Dr. Henderson Smith had already published (1928) an account of a mosaic disease of tomatoes, the so-called aucuba disease, caused by a filterable virus closely allied to tobacco mosaic and characterised by the brilliance of its symptoms and the high resistance of the virus to heat, ageing and chemical reagents. He failed to obtain any growth in cell-free media. He had also studied (1928) the transmission of potato mosaic (not then sub-divided into distinct diseases) to tomato and other hosts; and had begun an investigation (later carried further by Dr. Sheffield) into the intracellular inclusions which are characteristic of many virus diseases both in man and animals, and are exceptionally well exhibited in *Solanum nodiflorum* when infected with aucuba mosaic (1930). There is a persistent belief that viruses are an invisible stage in the life-history of visible bacteria, and some support is to be found in the fact that in certain virus diseases specific bacteria are regularly found to be present. Henderson Smith, however, showed (1933) that in tomatoes grown from sterilised seed under aseptic conditions and inoculated with filtered virus juice free from bacteria the disease developed normally without the appearance of bacteria, which should have appeared if they were a stage in the virus multiplication. Miss Jarrett (1930) investigated the streak which occurs in commercial tomato houses, and showed that it is not usually due to a mixture of ordinary mosaic with potato mosaic, as had been supposed, but is an independent virus

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disease resembling tobacco mosaic. She obtained no transmission with *Thrips tabaci*.

In collaboration with D. Mac Clement, Henderson Smith used the gradocol collodion membranes introduced by Dr. Elford to measure the size of certain of the plant viruses. They showed that they differed in size, as do the animal viruses, and arrived at estimates of the actual size of the particles as they occur in infective juice (1932).

Caldwell, in his first papers (1930, 1931) proved that aucuba mosaic does not travel through the plant in the water stream, as was generally assumed, and that it does not normally gain entrance to the water stream, and, if artificially introduced into it, cannot leave it and produce infection. Movement occurred only through living tissue, and the virus cannot pass across a completely dead area. In certain hosts the virus produced only a local reaction at the site of inoculation, in others it might travel through the plant, but produce symptoms only sporadically. Even in tomato the distribution was not uniform, the concentration being higher in the cholorotic areas. The carbohydrate and dry matter content of diseased plants is higher than in normal plants, and respiration is increased, but the nitrogen content was not materially affected.

Caldwell showed that the virus was particulate, and produced some evidence that it was either itself protein or bound to protein, but he was able to show that the claims that had been made at that time to have obtained it in crystalline form were unwarranted. He demonstrated the occurrence of more than one strain of aucuba mosaic, and that the presence of the one produced immunity to the other. He showed that this immunity was in some degree specific against allied strains, but inactive against virus not related to the immunising strain. In a study of the local lesions technique and the effect of adding chemical substances to infective juice he suggested a method by which it was possible to distinguish between the effect on the virus itself and that on the leaves used to test the mixtures.

Birkeland prepared sera against a number of different viruses grown in hosts serologically unrelated, and tested them by the precipitin method. The reactions gave additional evidence that virus is in itself antigenic ; and showed also that cucumber mosaic, tobacco ring-spot and tobacco mosaic are serologically distinct, while aucuba mosaic, tobacco mosaic and probably tomato streak are serologically indistinguishable.

F. C. Bawden joined the staff in 1936, replacing Caldwell, and in collaboration with N. W. Pirie of the Biochemical Laboratory Cambridge, began a series of investigations, which has given and is still giving important results. They (1937) isolated from solanaceous plants infected with three strains of tobacco mosaic virus nucleo-proteins with characteristic optical properties. These are infective at a dilution of $1/10^{10}$ and give specific precipitates with antisera at a dilution of $1/10^{7}$. Solutions of the purified proteins, if the protein content is greater than 2 per cent., separate into two layers, of which the lower is the more concentrated and is birefringent, while the upper shows anisotropy of flow. When centrifuged at

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high speeds these solutions deposit the protein in the form of a birefringent jelly. No enzyme preparation has been found which attacks these proteins at an appreciable rate, but the activity can be affected by a number of chemical agents, and the conditions under which the nucleo-protein complex breaks down were studied. It is suggested that in purified proteins the constituent particles are rod-shaped, and are built up by the linear aggregation of smaller units. There is evidence that in the plant part at least of the virus is not so aggregated.

Similar nucleo-proteins were isolated from cucumber plants infected with Cucumber viruses 3 and 4. These viruses have a host-range distinct from that of tobacco mosaic and differ more widely from the latter than do recognised strains of tobacco mosaic ; but they have many properties in common with the latter virus and have common antigens. When precipitated with acid or ammonium sulphate, the proteins form needle-shaped paracrystals, as does tobacco-mosaic virus.

Dr. Sheffield took up the investigation of the inclusion bodies already referred to. It had at one time been asserted that these were actually the virus itself in an amoeboid form ; but she showed that they were aggregations of cellular material, which, appearing first as separate small masses circulating in the streaming cytoplasm, coalesced to form eventually the complete inclusions. The process could be followed throughout in the living hair-cells of *Solanum nodiflorum*, and a film was prepared which showed the successive stages from the first appearance of the moving particles shortly after infection to the final completed body, which may eventually break down into protein crystals (1931). She attempted (1934) to parallel these conditions in healthy cells by treatment with substances known to coagulate cytoplasm. Most of the reagents used induced stimulation of the cytoplasmic stream similar to the initial stages of virus infection without real formation of true inclusions but with the salts of molybdic acid all the cytological abnormalities produced by aucuba virus could be imitated in the absence of any virus.

After a study of the development of the assimilatory tissue in Solanaceae she investigated by micropipette injection the susceptibility of the plant cell to virus, and found that individual cells varied greatly in their reaction. She also demonstrated the rôle that the plasmodesms play in the spread of virus by an examination of the stomatal guard-cells. These cells never contain inclusion-bodies, which occur in all other cells, and this immunity was attributed to their lack of plasmodesm connections.

In nature virus disease is commonly transmitted from plant to plant by insects, but how it is accomplished is difficult to understand. It is not, as a rule, simple external transference of infective material on the mouth parts of the insect : there is a specific relationship between the vector and its virus. Mrs. Watson (*née* Hamilton) took up the study of this problem. After developing a method of maintaining insects apart from the living plant (1930), she determined (1935) the volume of liquid taken up by the feeding aphis and the volume returned in the saliva as well as the relations of these volumes in artificial feeding and under natural conditions.

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She used different methods of estimation, including imbibition of radio-active solutions, of which very small amounts are measurable, and by the various methods obtained results which are reasonably consistent ; and she brought forward evidence that the quantities of virus transferred correspond to the amounts of liquid. This work was followed up by an extensive quantitative study, statistically controlled, of the factors affecting the amount of infection obtained by aphis transmission. Throughout the work she used a virus *Hyoscyamus* III, which she had isolated from an outbreak of disease in a crop of *Hyoscyamus* grown for commercial purposes. A number of striking results appeared from this investigation, e.g. that a maximum percentage infection was obtained during the winter months and a minimum during summer, and that the per-

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Smith, J. Henderson—" Experiments with a Mosaic Disease of Tomato." Annals of Applied Biology, 1928, XV, pp. 155-167, with 1 plate.

Smith, J. Henderson—" The Transmission of Potato Mosaic to Tomato." Annals of Applied Biology, 1928, XV, pp. 517-528, with 3 plates.

Smith, J. Henderson—" Intracellular Inclusions in Mosaic of *Solanum nodiflorum* " Annals of Applied Biology, 1930, XVII, pp. 213-222, with 3 plates.

Smith, J. Henderson—" Streak in Tomatoes Aseptically Grown." Annals of Applied Biology, 1933, XX, pp. 117-122.

MacClement, D. and Smith, J. Henderson—" Filtration of Plant Viruses." Nature, July 23, 1932, 2 pp.

Jarrett, Phyllis, H.—" Streak, a Virus Disease of Tomatoes." Annals of Applied Biology, 1930, XVII, pp. 248-259.

Jarrett, Phyllis H.—" The Rôle of *Thrips tabaci* Lindeman in the Transmission of Virus Diseases of Tomato." Annals of Applied Biology, 1930, XVII, pp. 444-451.

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Caldwell, J.—" II. Further Studies on the Movement of Mosaic in the Tobacco Plant." Annals of Applied Biology, 1931, XVIII, pp. 279-298, with 4 plates.

Caldwell, J.—" III. Aucuba or Yellow Mosaic of Tomato in *Nicotiana glutinosa* and other Hosts." Annals of Applied Biology, 1932, XIX, pp. 144-152, with 1 plate.

Caldwell, J.—" IV. The Nature of the Virus Agent of Aucuba or Yellow Mosaic of Tomato." Annals of Applied Biology, 1933, XX, pp. 100-116.

Caldwell, J.—" V. The Movement of the Virus Agent in Tobacco and Tomato." Annals of Applied Biology, 1934, XXI, pp. 191-205, with 1 plate.

Caldwell, J.—" VI. Some Effects of Mosaic on the Metabolism of the Tomato." Annals of Applied Biology, 1934, XXI, pp. 206-224, with 2 plates.

Caldwell, J.—" VII. Experiments on the Purification of the Virus of Yellow Mosaic of Tomato." Annals of Applied Biology, 1935, XXII, pp. 68-85, with 2 plates.

Caldwell, J.—" On the Interactions of Two Strains of a Plant Virus : Experiments on Induced Immunity in Plants." Proc. Roy. Soc. Lond., 1935, B., 117, pp. 120-139, with 3 plates.

Caldwell, J.—" Factors Affecting the Formation of Local Lesions by Tobacco Mosaic Virus." Proc. Roy. Soc. Lond., 1936, B., 119, pp. 493-507.

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centage infection (which increases with increased feeding time on the healthy plant) decreases rapidly with increasing times on the infected plant from two minutes to one hour.

In 1932-1933 Mrs. Watson investigated an outbreak of disease in commercial grown *Hyoscyamus*, from which she isolated three viruses, two of them new. In a crop of this kind, which is limited and valuable enough to warrant the expense, it seemed that control by spraying might be practicable ; and it was found that the aphis infestation and consequent infection were reduced thereby. The greatest effect was obtained with weekly sprayings. The influence on yield was less evident, but as a result of weekly spraying in the first year a 30 per cent. increase was obtained in the third crop taken in May of the second year.

As the work of the other Departments has been recently described in full it is not necessary to do more than mention some of the chief lines of work being done in each.

SOIL CULTIVATION AND MANAGEMENT

These investigations are in charge of the Soil Physics Department : an extended account was given in the Report for 1936. Evidence has been accumulated that the purpose of cultivation is to keep down weeds, and operations additional to what is required for this may prove ineffective or even detrimental. The importance of preparing a good seed bed is recognized though some of the rather striking differences in appearance of crop resulting from different methods of preparation do not lead to corresponding differences in final yield.

Soil moisture.—The water relationships of soils have been much studied as being among the most important factors in soil fertility. Water easily moves downwards in the soil under the force of gravity but in other directions its movement is both slow and small in amount. Evaporation seems to occur *in situ ;* plant roots grow to the water, the water does not move to the roots. The investigation of this subject would be greatly facilitated if a trustworthy method were known for the direct measurement of water in the soil and some progress has been made in this direction.

The colours of soils.—Soil surveyors regard the colour of the soil as one of the properties helpful in classification. An improved method of recording colour devised by Dr. Schofield was found to be so valuable that an important firm of instrument makers has acquired the patent and taken over his assistant for the purpose of further developing it.

Soil structure.—Methods are being devised for studying in detail the structure of the soil.

STATISTICAL DEPARTMENT

During the last few years the scope and work of the Statistical Department have changed considerably. The staff had at first to develop methods ; now these methods are used for the solution of problems presented by other departments. At the present time there are three main lines of work :

(1) The improvement of designs for field experiments whereby these may become more useful than at present.

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