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WASTAGE OF WORLD FOOD SUPPLIES THROUGH DISEASES AND PESTS

By

Sir John Russell

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The following address given by Sir John Russell opened the International Agricultural Conference held at the Fernhurst Research Station of Plant Protection Ltd., in June, 1951.

The address is such a well balanced account of the whole subject of plant pests and diseases that, in spite of its somewhat technical nature, it cannot fail to interest all those engaged in the production of tea in Ceylon.

From the earliest times cultivated crops have suffered from diseases and pests, but little could be done in the way of control till the causes were discovered. Plant Pathology was the latest to develop of all the sciences dealing with crop production : it is little more than 50 years old and even now there are great sections of it where our knowledge is very limited. The subject is of growing importance, because of the growing seriousness of the world food situation : India's recent food troubles, averted only by the rushing in of large quantities of grain grown by the Western peoples, show how grave the problem is. The steady expansion of the world's population, and the continuing loss of land due to natural causes like erosion and flooding, and to human activities such as the withdrawal of land from agriculture to put it to other purposes, continually make the problem more difficult. It is imperative that the wastes and losses due to diseases and pests should be reduced to a minimum. Where food is scarce it certainly cannot be spared for insects or fungi. Entomologists, mycologists and plant pathologists in this country and overseas have long emphasised the need for action, and now the Food and Agriculture Organisation of the United Nations has taken the matter up.

The losses caused by plant diseases and by weeds can only be estimated very approximately. Insect, fungus and bacterial populations are always with us and so long as their numbers remain small the damage they do is hardly perceptible except to an expert and so is disregarded. Plants make considerable provision for loss ; more tillers are produced by grain crops than can produce full sized heads, more blossom opens on fruit trees than can set good quality fruit. Destruction of some of these by pests does not necessarily lower the final yield. But there are always some losses, which, however, cannot be estimated because on any particular field the yields vary from year to year according to weather conditions and there is no fixed yard stick. A figure of 10 per cent is frequently quoted but it has no statistical basis and is really based only on guess work. A Plant Disease Survey has now been instituted under E. C. Large of the Ministry of Agriculture Plant Pathology

Laboratory, Harpenden, and more definite information may be expected. In countries of less advanced agriculture where the means of detecting and combating diseases are less effective the losses are almost certainly higher than here, and if ours are put at 10 it would probably not be unfair to put losses in many other countries at 20 or more per cent of a healthy crop. Estimates of this kind may be crude but they have a certain pragmatic value; expressed in money terms they look very impressive especially when as often happens, local scarcity prices are used, and they may induce hesitating Ministers to sanction activities that ought in any case to be undertaken. In another way too they are impressive: the losses as estimated are usually of the same order as the estimated shortage of food supplies, and it is probably true to say that the amount of food now destroyed in the field and in store by pests controllable on present knowledge would amply supply the world's present food deficits.

Physiological and Cultural Methods of Avoiding Diseases and Pests

Plant diseases fall roughly into two groups—physiological, due to deficiency or excess of some essential factor, and those caused by some pathogenic organism coming from outside. At present the physiological diseases attracting most attention are those due to deficiencies of the trace elements boron, copper, manganese, molybdenum and zinc. These eluded investigation till chemists had elaborated methods of working with the very minute quantities involved: agricultural science always has to limp behind pure science. Symptoms and methods of diagnosis and treatment are now being worked out: you are all familiar with Dr. Tom Wallace's publications from Long Ashton and W. A. Roach's work at East Malling. The diseases occur widely over the world: Australia has some striking examples.

The effect of pathogenic organisms on the plant depends in many instances on the conditions of growth: usually the organism can attack the plant only in one stage of its development, and the plant likewise is susceptible to attack only over a certain period of growth. Any cultivation or manurial device that throws plant and organism out of step protects against attack. Farmers at home have long since learned to sow oats early in order to avoid fritfly. H. F. Barnes at Rothamsted controlled gall midges on Meadow Foxtail grass by cutting back the grass a few weeks before flowering—the period of oviposition of the midges. This delayed flowering but not the midges. The two were put out of step and the damage was reduced from a former 90 per cent to 10 per cent.[1] Early maturing wheats are sought in Canada to avoid late rust, cotton in the Sudan is sown after the rains to avoid Black Arm.

The manuring of the crop affects its rate of growth and the structure and composition of the plant tissues: both are closely connected with susceptibility to attack. Much experimental work has been done at Rothamsted and elswhere to secure optimum physiological conditions for the crop, and this, combined with sound field sanitation—the destruction of infectious material—gives a large measure of protection even where there is a lively risk of infection. I have a vivid recollection of going round H. O. Larsen's glass houses in the Lea Valley and seeing his tomatoes and cucumbers beautifully sturdy and healthy while in the neighbourhood there were houses infested with a wide range of diseases. Cultural methods of dealing with two troublesome wheat diseases have been worked out, for Eyespot by M. D. Glynne, and for Take All by S. D. Garrett; both depend on favouring the plant at the expense of the fungus. A particularly neat method was devised by an ingenious farmer F. P. Chamberlain of Benson, Oxfordshire, and put on a scientific basis by S. D. Garrett. The barley is undersown with trefoil and rye grass: this grows during the autumn and exhausts the available nitrogen in the soil so that the fungus is starved. In early spring the mixture is ploughed in and

[1] For fuller discussion of "Preventive Entomology" see C. B. Williams Annals Applied Biology, 1947, Vol. 34, pp. 175-185.

quickly decomposes, producing ammonia and nitrate in the soil that gives the next crop of barley such a good send off that it remains free from serious attack. In this way he has been able to grow at least twelve successive barley crops all healthy and yielding well.

In India mixed cropping has kept down certain soil diseases. R. S. Vasudeva[1] has collected a number of instances. In one trial cotton grown alone suffered to the extent of 52.5 per cent from root rot (*Rhizoctonia*), but when *Moth* (*Phaseolus aconitifolius*) was grown with it the mortality fell to 1.8 per cent. He attributed the effect to a lowering of the soil temperature.

The cultural methods of controlling disease will be greatly strengthened when it becomes possible to forecast the probability of a great increase in numbers of particular insects from a study of the preceding weather conditions such as C. B. Willinms has been doing[2]. Forecasting of the best dates for spraying has long been done for the fruit growers of South East England by Dr. A. M. Massee, based on field observations of the detailed fluctuations in the population of various pests, from week to week and month to month, in orchard and farm.

This undoubted connection between nutrition of the plant and its susceptibility to disease has been emphasised by the so-called Humus group, followers of the late Sir Albert Howard, who hold that organic material which has once lived is alone suitable as food for plants. Synthetic substances even when chemically identical with those of organic origin are supposed to cause abnormal development, a lower value as food and lower resistance to disease. I know of no evidence in support of this view.

The Search for Resistant Varieties

The long known difference in susceptibility to disease of different varieties of the same crop has been utilised in three ways for plant protection. Seed or tubers from healthy plants growing among a diseased crop are kept separate and grown again for a few generations to ensure that the plants really are resistant to the disease. Most of the older resistant varieties were obtained in this way. This method successfully dealt with Wart Disease of potatoes which appeared in Cheshire in 1902 and proceeded to work its way across England : nothing could be done against it ; even withholding the crop was ineffective, for the fungus could remain viable in the soil for 14 years or more. In 1908 however immune varieties of potatoes were found and from these many new ones have been raised by plant breeders. Trouble may crop up again, however : in 1942 two new races of the fungus were found in Germany capable of attacking some of the immune varieties[3] So far they have not been observed in this country, but they may still come. Alternatively a resistant variety found in some other country is imported : a classical example is the importation into France of American vine root stocks resistant to Phylloxera in the 1870's and 80's.

The third method, and by far the most certain, is by cross breeding : having found a variety possessing resistance this quality is transferred to non-resistant varieties posessing the other properties desired. This method was developed in Great Britain by Rowland Biffen, who at Cambridge had studied genetics under William Bateson, and Plant Pathology under Marshall Ward, and proceeded from 1900 onwards to fuse these two subjects. He worked with wheat, which is well suited to genetical experiments, and showed that some of its morphological characters, roughness of chaff, and colour in the seed coat, were simple Mendelian

[1] Proc. 36th Indian Sci. Congress.

[2] Proc. Roy. Soc. B. 1951. Vol. 138, pp. 130-156.

[3] H. Braun, Z. Pfl. Krankh, 1942, Vol. 52, pp. 481-6.

characters; and then proceeded to find whether resistance to Yellow Rust (*Puccinium glumarum*) was also. It was: and he produced rust resistant Little Joss by crossing a Russian Ghirka wheat, resistant to rust, with Square Heads Master, an old English variety with some admirable qualities but unfortunately susceptible to rust. This was the first instance in this country of scientifically building up a new variety by assembling in one plant desirable characters from two or more other sorts. Little Joss was a great success and the method has been much used since.

There was an element of luck in Biffen's work. Resistance to disease is not usually a single Mendelian character as it seemed to suggest. In general, resistance is complex, involving several genes, and depending on numerous morphological and physiological characteristics of the plant: the thickness of the cuticle, composition and osmotic pressure of the sap, and the general suitability of the cell for the growth of the invading fungus once it has got in. Resistance comes about in two ways: the organism may not be able to effect an entry, or, if it does get in, the plant may prevent it doing harm by sealing off the invaded cells, or in some other way. By reason of this complexity resistance is rarely, if ever, complete though it may be so good as to amount almost to immunity in the field.

The Black Stem Rust of wheat (*P. graminis*) presents more serious and difficult problems. Great Britain is practically free from this disease; it occurs in south west Wales, in the corner where Cardiganshire and Pembrokeshire join—where its alternate host, the barberry grows; but in the great Continental wheat regions of North America, Australia and Eastern Europe where most of the world's wheat is grown, it has caused terrible losses. In 1916 it was estimated to have destroyed 280 million bushels of wheat in Western Canada and the United States. Meanwhile investigations were proceeding at the Minnesota Experiment Station under the brilliant leadership of E. C. Stakman, later also in 1925 they were started at Winnipeg. Stakman showed that the fungus existed not only in different varieties, each adapted to a particular kind of cereal, but in many different physiological races having different degrees of virulence. He isolated the first of these races in 1917; by 1948 no fewer than 220 were known of stem rust, and 130 of leaf rust; new ones are constantly being produced either by mutation or sexually, particularly on the alternate host, the barberry. This of course greatly complicates the work of the plant breeder. The first commercially successful wheat resistant to stem rust was Ceres, introduced by the Minnesota Station in 1926; it lasted ten years. A new strain of the fungus had appeared: Race 56: which could attack it; this gradually spread and by 1934 was the most prevalent race in the United States: in 1935 it made a virulent attack in one of the worst rust epidemics the States had known— and Ceres went down badly. The Minnesota staff then introduced Thatcher which was resistant to Race 56: unfortunately it was very susceptible to orange leaf rust and to scab. It was therefore crossed with Hope, a variety resistant to leaf rust and after twice backcrossing to Thatcher gave a new variety, Newthatch, resistant to both stem and leaf rust.

Meanwhile the Canadian investigators at the Rust Laboratories at Winnipeg had been busy; in 1939 they produced Regent, which became the most widely grown variety in the rust districts and later they improved on this with Renown and other sorts.

However a new and still more virulent strain of the fungus, Race 15 B, has been observed near barberry bushes in the Eastern States; this can attack Newthatch and all other varieties of wheat now grown in the States. It is not yet widely distributed but that is only a matter of time. Other strains still more virulent than

15 B have since been found, some of them in Western Canada. Both the Canadian and the Minnesota plant breeders are producing new varieties of wheat in readiness for them when they spread[1].

Potato diseases are becoming increasingly important now the world food shortage is necessitating extended cultivation of this crop : in conditions as diverse as those of Scotland and India it produces twice as much food per acre as grain, often more. Unfortunately it is subject to a number of diseases and pests : fungus, insect and virus. The most terrible epidemic of plant disease on record was that which resulted in the appalling Irish famines of 1845 and later years[2], caused by the fungus, *Phytophthora infestans.*

Control afterwards became possible by spraying with a copper compound, but plant breeders have long been trying to avoid the disease by producing varieties of potato resistant to it. The methods are the same as for wheat : the world is searched for wild or cultivated varieties resistant to *Phytophthora*, and this property is then transferred to varieties lacking it though desirable in other ways. Some undesirable properties may also be transferred at the same time and these have to be got out by back crossing and selection. R. N. Salaman is the pioneer in this country. Among hybrids of a Mexican dwarf potato, *Solanum demissum,* he found some possessing a high degree of resistance. Crossing these with British susceptible varieties he obtained new resistant sorts possessing also good table and field properties. Then came a bad blight year (1933) and the resistant varieties went down. Salaman suspected that a new biotype of the fungus was concerned, and this proved to be correct : he called the old race " A " : to this his hybrids were resistant, to the new race " B ", however, they were not. A further search discovered the B-resistant gene and this was carried into a new variety. Continuing this synthetic process Salaman assembled in one plant resistance to blight and wart diseases, tolerance of virus diseases, and good field and table qualities : specimens were shown by him at the Chelsea Flower Show in 1939.[3] The work has been continued by W. Black at Cortstorphine.[4] In due course a third biotype " C " appeared to which the A B resisters succumbed. Again the early generations of *S. demissum* seedlings had to be searched : fortunately strains resistant to " C " were found ; and fortunately also the new hybrids resistant to A, B and C were also resistant to about 10 other strains of the fungus found in Germany. Meanwhile a still more virulent strain " D " has appeared in Tanganyika which can destroy several groups of the ABC resisters. It does not appear to have reached this country yet, but this may be only a matter of time. It is being investigated in Kenya by R. M. Nattrass, who has already found two other strains, E and F, also originating in Tanganyika but now widely spread over East Africa on tomatoes and potatoes.

Resistance to these various strains is not a simple property : four major dominant genes appear to be concerned in resistance to A, B and C. Nor is the transfer quite simple, for along with resistance some undesirable qualities are likely to be carried in, especially from a wild parent, and much backcrossing and selection may be necessary to get rid of them. When that is done desirable farming and commercial properties still have to be imparted.

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[1]The Minnesota work has been described by E. C. Stakman in *Science in Progress* (Yale Univ. Press), 5th Series, 1947, and the Canadian work by C. H. Gouldson, T. M. Stevenson *et al* in investigations on oats at Aberystwyth are described by E. T. Jones, *ibid* 199–204.

[2]For its history, see E. C. Large's very interesting book *Advance of the Fungi* (1940).

[3]R. N. Salaman (See also his book *The History and Social Influence of the Potato.*) Empire Jl. Expt. Agric. 1949, Vol. 17, pp. 238–244.

[4]W. Black *ibid.* pp. 114–124.

Remarkable results have been achieved : Black records that in four generations of breeding from the wild *S. Demissum* a variety has been produced combining field immunity, or a high degree of resistance, to blight strains A, B and C ; to wart disease ; several strains of virus A, X and Y ; leaf roll ; scab and storage diseases with good cropping capacity and cooking quality. It looks as if perfection is at last reached—but, he adds rather sadly, these qualities alone will not necessarily ensure success under general cultivation.

Breeding for resistance appears to be the only way of coping permanently with virus diseases of potatoes, though much could be done by fuller use of virus-free seed. Genes are known resistant to viruses A and X causing Mosaic disease and resistant varieties have been bred ; resistance to Y also causing Mosaic disease has proved more difficult to achieve. Some varieties are tolerant to a virus and can be infected without suffering injury, *e.g.*, King Edward and virus X— but of course they become carriers. Hop mosaic had been alleviated by E. S. Salmon, who produced hybrid hops tolerant of the disease and carrying it, but suffering no loss.

Fortunately, Dr. Kenneth Smith is here to discuss the possibilities of control of virus diseases, and equally fortunately F. Bawden is to open the discussion. The fundamental investigations they and their colleagues at Cambridge and Rothamsted are doing on the nature and properties of the different viruses and their relations to the plant must in the end furnish the best means of control.

In the meantime much can be done to evade the virus diseases by using only clean seed or stocks. Salaman has built up virus-free stocks of potato seed at Cambridge. The East Malling staff in their detailed studies of the viruses of soft fruit have isolated strains of strawberries and of raspberries, either free from known viruses or else containing only a single virus not known to be important ; in both cases growers were losing considerably, but these clean stocks have given new life to the industry.

But however successful it may be for a time, the search for resistant varieties is always dogged by the fear that some new strain of the pathogen may be produced before which the resistant varieties go down. It is like a race where a new competitor is always likely to turn up a lap ahead. Nevertheless it has given remarkably good results and is one of the surest ways of dealing with plant diseases.

Plant breeding against insect pests has also been done to some extent ; it may be more permanent unless the insects are able to mutate. The outstanding example in this country is the breeding of new apple stocks resistant to Woolly Aphid started at East Malling in 1920 by R. G. Hatton and M. B. Crane of the John Innes Horticultural Station then at Merton. Resistant Northern Shy stocks were crossed with the original East Malling stocks and from among many thousands of seedlings resistant strains over the whole vigour range have been selected for wider trial. The work has been extended by Tydeman, who is trying to produce resistant scion varieties of suitable quality.

R. D. Knight in the Sudan is putting longer and thicker hairs on to the leaves of the cotton plant in order to prevent the sucking Jassid insect from reaching the cells. He has already carried in two out of the three factors for resistance to Black Arm ; likewise he has added resistance to Leaf Curl which is controlled by minor genes ; he hopes further to add valuable cropping and spinning qualities—a really superb piece of plant synthesis.

Direct Action against Pests : Grain, Seed and Stored

The most effective way of dealing with a harmful organism is to kill it, and modern chemistry has provided many powerful agents for doing this. But undesirable secondary results may follow, especially with insects. An agricultural field or an orchard normally contains a very mixed insect population, presumably in some sort of equilibrium with their surroundings and each other ; on the whole it may do little harm to the crop. When the equilibrium is disturbed one species may begin to multiply rapidly and finally reach the proportions of a pest. An outstanding example is the development of the Fruit Tree Red Spider Mite from an insignificant member of the orchard population to a serious pest, following upon the development of spraying programmes designed to control other orchard pests.

The simplest case of affording protection by direct killing of an injurious pest is in dealing with grain either before sowing or in storage. In neither case is any complication likely to result so long as the grain itself is not injured or, if it is being stored, does not absorb anything likely to be harmful to the consumer. Treatment of seed corn as a preventive against Smut is very ancient : seed borne fungi that remain outside the seed were first controlled by dusting the seed with copper carbonate ; this was replaced later, however, by the much more effective organic mercury compounds. Wheat, barley and oats in England and millet[1] in the Sudan are all protected in this way. Most British merchants treat the seed before selling it. W. A. R. Dillon Weston reports that, in the season 1921-2, 32 per cent. of the wheat samples examined at the Official Seed Testing Station, Cambridge, contained bunt balls ; since that time the percentage has steadily fallen and is now only about one. Leaf stripe of barley (*Helminthosporium*) is now so effectively controlled that College lecturers sometimes have difficulty in getting samples for their students.[2] The mercury compounds are of the type R-Hg-X where R is the radicle and X the acidic group. R and X can both be changed in a multitude of ways[3] : the toxicity can thus be adjusted so that the fungus can be killed but the seed spared. The solubility can also be varied allowing for both dry and wet treatments. One of these preparations is used in the Sudan to remove *B. Malvacearum* that causes Black Arm in cotton. Loose Smut of oats and barley, however, cannot be chemically controlled as the fungus is inside the seed.

The need for storing food grains free of all insect and fungus pests has become urgently important in view of the widespread unsettled conditions and serious shortages of today. There have been some serious losses : some months ago it was deemed expedient to store 25,000 tons of grain at Khartoum : 15,000 tons went bad. Even where preservation is perfect the grain may be effected. The Pest Infestation Laboratory which is doing good work on this subject has shown the DDT used to protect wheat grain appears in the flour and the bread, and in the tissues and excreta of hens and rats fed thereon, and as a metabolite in the urine of a man who had eaten an ounce of it.[4]

Protection of the Living Plant

(1) Biological control of insects and fungi

It is much more difficult to deal with the living plant in its relation to the population of mixed insects such as occur in the field, the orchard or the glasshouse. The gentlest method where it is practicable is to encourage the parasites or predators of the harmful insect. This biological control has all the attractiveness of any

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[1] this with copper carbonate.

[2] The rice species, however, is still common in India, and does much damage ; it was indeed an important factor in causing the Bengal famine.

[3] Much of the chemical work is unpublished and has been done by the manufacturers, particularly during the last war by I. G. Farbenindustrie. The pioneering testing in this country was by W. A. R. Dillon Weston and J. R. Booer. Journ, Agricult. Sci. 1935, Vol. 25, pp. 628–648.

[4] F. P. W. Winteringham *et al.* Sci. Food & Agric. 1950, Vol. 1, p. 214. The radio-active tracer technique was used in this investigation.

proposition offering something for nothing : unfortunately successes are comparatively rare. A striking instance is the control of Cottony Cushion Scale insect of citrus introduced into California from Australia without its natural enemies so that it was able to romp away and do considerable damage. But its predator, the Vedelia ladybird beetle, was brought in from Australia and reduced it to manageable proportions[1]. Another has been the almost complete extermination in Ceylon of the serious tea pest, Tea Tortrix (*Homona coffeearia*) by the parasite *Macrocentrus homonae* introduced from Java. This still maintains a high population level in spite of the disappearance of Tortrix, showing that it has been able to establish a balance with other members of the insect population.

The control of coconut moth in Fiji by an introduced parasite formed the subject of an interesting exhibit at the 1951 South Bank Exhibition.

We have a good example in our own country, though as far as I know, only one. A white fly was doing considerable damage in the Lea Valley glasshouse region : the Experiment Station introduced a Chalcid which parasitises its larvae : the fly is no longer a serious pest. In the Kenya coffee plantations a coffee mealy bug which has come in from Central Africa was doing much damage : Dr. Le Pelley was sent on a world tour to find some parasite : he found in Uganda a small wasp-like Hymenopterous insect that served admirably. From the Delhi Agricultural Research Institute a *Trichogramma* is distributed which parasitises the eggs of a stem borer and a root borer of sugar cane (*Argyria sticticraspis* and *Emmalocera depressella*) though I heard varying accounts of this in India.

The possibility of biological control of pathogenic soil fungi was recognised long ago when it was observed on culture plates that some forms are definitely antagonistic to others[2]. Two general methods have been studied. The saprophytic organisms may be stimulated *en masse* to multiply vigorously and so starve or asphyxiate the pathogenic forms. This was the principle underlying Millard and Taylor's control of potato scab in 1927 by heavy green manuring which greatly stimulated the antagonistic and competing organisms : the principle was used also by A. W. Henry and G. B. Sanford for dealing with cereal root rots in Canada and by S. D. Garrett in controlling Take-all in England.

The long known antagonism is now traced to antibiotics produced by some of the organisms, and fascinating prospects have recently been opened up of using these substances as control agents. Penicillin and Streptomycin are already widely used against human diseases : they have also been used against a bacterial crown gall killing trees in the gardens of wealthy Americans in Arizona[3]. This method is hardly likely to become general. But antibiotics produced in the soil may be used *in situ*. J. Rishbeth at Cambridge showed that *Trichoderma viride* which grows on the root surface of pine trees in acid soil produces the antibiotics gliotoxin and viridin which protect the root against the potent disease fungus *Fomes annosus*[4]. Very promising work on the subject is being done by P. W. Brian and his colleagues at the Butterwick Research Laboratories at Welwyn. They have isolated and studied various of the antibiotics produced in soil, and, perhaps most remarkable of all, they showed that one of them, griseofulvin, taken up from the soil by the plant, acted as a systemic fungicide protecting lettuce foliage from grey mould (*Botrytis cinerea*) and tomato foliage from early blight (*Alternaria solani*).

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[1]Quoted from R. A. E. Galley.

[2]See for example M. C. Potter, Journ. Argic. Sci. 1950-10, Vol. 3, pp. 102–7.

[3]J. C. Brown, Internat. Bot. Congress, Stockholm 1950.

[4]For other examples see the very interesting discussion by S. D. Garrett in Biological Reviews 1950, Vol. 25, pp. 220-254.
The subject was also discussed at Stockholm in July, 1950 at the Internat. Botanical Congress.

(2) **Chemical Control of Fungi and Insects**

This can be complete but many difficulties may arise. The agent used to kill the insect or fungus may injure the plant doing more harm than the pest would have done. With fruit trees this danger is reduced to a minimum in winter, and potent washes are now available for killing eggs and resting forms without injury to the buds. The danger is much greater when the tree is in leaf but here the vegetable insecticides, pyrethrum, derris, nicotine, quassia, etc., are useful ; they are toxic to certain insects but harmless to the plant and also to domesticated animals. Pyrethrum is so much in demand that it is cultivated on a large scale in Kenya and is indeed, one of Kenya's chief exports, being sent largely to the United States. Since F. Tattersfield and his colleagues at Rothamsted isolated the toxic principles there is always the danger that they may be synthesised and that the natural product may be driven off the market as indigo was in the early days of this country, but a Research Group has been established to produce higher yielding varieties and to lower the costs of production.

Valuable though they are, these vegetable pesticides are limited in their application : chemical substances offer much wider scope. A few have been in use for many years, particularly Bordeaux mixture and sulphur : indeed Bordeaux goes back to the time before spraying machines were available and the operator had to walk along the rows of vines with a bucket of the mixture in one hand and a switch of heather in the other, flicking the mixture on to the plants as he went along[1]. The early substances were simple inorganic compounds of copper, arsenic or sulphur, but great advances have been made in recent years by the introduction of complex organic compounds, which can be prepared in long series with graduated properties capable of almost unlimited modification : and as a result of the modern combination of organic and technological chemistry they can be made on the large scale ; some among these are able to kill almost any insect or fungus.

In view of the many fundamental resemblances between plant and animal cells it is remarkable that they should differ so much in their reactions to poisons. The historic fungicidal elements are copper and sulphur, but neither are insecticides. Copper is particularly interesting because it is essential to fungal growth in minute quantities : indeed in Holland *Aspergillus niger* is used to test whether soils contain enough copper for plant growth. But the limit is rapidly overstepped and it was early discovered that two or three parts of copper sulphate in 10 million of water prevent the complete development of the spores of *Peronospora*. Improvements of these copper and sulphur sprays continues but the great progress has been with the mercury organic compounds. Reference has already been made to their use as seed dressings : phenyl mercury chloride and phenyl mercury acetate are also used as early sprays for the control of apple scab. But there are wider possibilities : cerium, cadmium and uranium salts are also toxic to fungi ; those of esmium and silver apparently even more so than those of mercury[2].

But with all the advances made there is as yet no good soil fungicide for use in the field. Formaldehyde has long been used in glasshouses against foot rot, Verticillium Wilt and other fungus diseases, and still remains the most efficient soil fungicide. Following the analogy of the high efficiency in their respective fields of organic phosphorous and organic mercury compounds, it might be anticipated that organic sulphur compounds would prove useful, but that remains to be seen.

These fungus problems are being treated by Mr. Cronshey and we may expect a useful discussion on them.

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[1] E. C. Large. Advance of the Fungi ; p. 229.

[2] S. E. A. McCallan and F. Wilcoxon, Contrib. Boyce Thompson Inst. 1934. Vol. 6, pp. 479–500.

Chemical Control of Insects

The most spectacular advances however have been with the insecticides, and here the chemists have built up synthetic substances of great complexity the manufacture of which is a marvel of chemical technology. One of the first to capture the imagination of the world was the Swiss product D.D.T. which has proved extraordinarily effective for a wide range of purposes : in the home against the housefly, in tropical jungles against the tsetse fly, in grain stores against weevils—although houseflies and other insects can become resistant to it. Like the other organic insecticides it is selective, potent against some but sparing others, and it soon appeared that spraying with D.D.T. while effectively destroying one lot of insects, allowed another lot to flourish and become a pest. Its use was followed by infestation of Fruit Tree Red Spider Mite and Woolly aphis in this country, by increases in the Egyptian Boll Weevill in the Sudan and in the numbers of Red Banded Leaf Roller in Canada where it was used against the Codlin Moth. This is, of course, part of the price to be paid for selectivity : it is an extremely valuable property but its possession means that the entomologist must know exactly which members of an insect population will be killed and which spared : he must then be able to forecast the probable effects of the insecticide in setting up a new population.

The British gamma benzene hexachloride (called B.H.C. for short) is no less potent and may prove more generally useful.

Still more potent insecticides are becoming available. Phosphorus is proving as useful a centrepiece for the entomologist as mercury for the mycologist ; some of its complex organic compounds, *e.g.*, parathion, are remarkably toxic to aphids and mites—insects resistant to many other insecticides. Unlike D.D.T. and benzene hexachloride they may be harmful to men and domestic animals : proper precautions must be taken in using them. Mr. Stapley is giving us an interesting comparison of these three substances.

Meanwhile, the means of distributing the insecticides and fungicides have been improved out of all recognition especially for large scale work. Low volume mist sprayers have greatly reduced the quantity of material needed and have increased its potency. Operations are now practicable that would have been impossible a generation ago. In the Sudan last year nearly 78,000 acres of cotton in the Gezira were sprayed against Jassid, and another 15,000 acres in the White Nile : it was done from a helicopter : in no other way could so large an area have been treated in time. Another important development has been a great extension of spraying by expert contractors.

An Old Problem Solved. Soil Insecticides

These new materials have solved a problem which had long baffled investigators: they have provided an effective soil insecticide for field use. The French vine growers long ago used carbon disulphide against root lice on their vines, and English tomato growers in the Lea Valley glasshouses used Cresylic acid against root eelworm : rather large quantities were needed because it decomposed fairly quickly in the soil. We at Rothamsted suggested putting in chlorine atoms to make it more stable and to intensify the action but this was not at the time practicable. None of these substances could be used on the farm, and wireworm, perhaps the worst of our soil insects, was unconquered. Well do I remember our anxiety during the first world war because of the great loss it caused in wheat grown on the ploughed up old grassland : even during the second war losses were reduced only by suiting the cropping to the density of the wireworm population as estimated by methods worked out during the interwar period. Field observations indicated losses averaging 0.6 cwt. per acre of wheat and oats for each 100,000 wireworms per acre, and as the numbers might not infrequently be of the order of one million, the aggregate losses were considerable[1]. But now B.H.C. has proved an effective control agent for farm use. It can be mixed with an organic mercury compound and applied to the seed so as to protect against both wireworm and seed-borne fungi.

Eelworms which do so much damage to potatoes, sugar beet and other crops, have proved particularly difficult to deal with and we shall all listen with great interest to what Dr. Holmes will have to say on the subject.

A New Approach : Systemic Insecticides

In the early 1920's, J. Davidson at Rothamsted showed that pyridine fed to broad beans made them distasteful to aphids. No practical field method could be worked out, however, for protecting the crop and the matter dropped. Entirely new possibilities of control were opened up by a group of organic phosphorus compounds which are absorbed by the plant and render it poisonous to insects feeding on its sap. They are thus perfectly selective, killing the insect that is about to damage the plant but leaving its natural enemies untouched.

These systemic insecticides seem to offer a way of dealing with the virus diseases transmitted by aphids. The ordinary insecticides come too late : the disease may already have been transmitted before the act, the systemic insecticides may prevent the infection. An attempt is being made in West Africa to use them against the dreaded Swollen Shoot disease of Cocoa which has caused serious economic and political troubles. They cannot cure trees already affected but they can protect unaffected trees. They have the further advantage that they enter the plant and are not washed off like the ordinary insecticide ; their presence may be objectionable or even harmful if the plant is to be used as human or animal food. This applies to all of the modern insecticides and emphasises that they should be used with great care and not applied near the time of harvest. S. H. Crowdy and R. L. Wain have demonstrated systemic fungicidal activity in compounds of similar structure to active plant growth regulators.

Herbicides and Growth Promoters

These complex organic insecticides and fungicides represent points in a chain of compounds of similar chemical pattern where toxicity to the harmful organism is sufficiently marked to put it out of action, but the toxicity to the plant is sufficiently low to cause no injury. A change in the pattern may modify these effects and bring into prominence the toxic action on plants, any insecticidal properties being less important. These substances are the herbicides and some among them that are selective in their toxicity are being used as weed killers. Some are directly poisonous, others are of the hormone type and act presumably by disturbing the physiology of the plant. These were discovered in 1941, and will be described to us by Dr. Sexton and Dr. Templeman. Some of them, notably 'Methoxone' and 2, 4 D, have come into wide use both in cereal cultivation and for grass land. No less than 13½ million acres are reported to have been treated in the prairie provinces of Canada in 1950 against only about half that acreage in 1949. By obviating the need for special cultivations they reduce not only the cost of production but, in semi-arid condition, the risk of soil erosion also. In any conditions weeds cause considerable loss in early stages of crop growth ; later on the effect is less harmful and may even be beneficial in arid regions liable to erosion. But these herbicides must be used with great care as many crops are extraordinarily sensitive to them; as little as 0.002 mgm. of 2, 4 D borne by the wind affected cotton plants[2].

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[1] *See* Wireworms and Food Production, Bull. 128. Min. Agric. and Fisheries.

[2] Staten, Dunlap and others quoted in " Advances in Agronomy " Vol. II. 1950 (Academic Press N.Y.)

The Increase of Plant Diseases and Pests

The present century has seen an unprecedented increase in our knowledge of insect and fungus pests and in the means available for combating them. But there has also been an enormous increase in the number of the pests and in their recorded prevalence. To some extent this is due to closer observation and better diagnosis : some of the diseases may be of long standing but only recently studied, such as Eye Spot and Take All of wheat. Many of them have come in from other countries, and modern transport is so rapid and multifarious that permanent exclusion of any pest capable of living in our conditions and feeding on any of our crops is extremely difficult if not impossible. America has, during this century, supplied us with American Gooseberry Mildew and Wart disease of potatoes ; the Colorado beetle has not yet secured a footing though only because of much watchfulness and now preventive spraying. We may still get the very serious *Thecaphora Solani* at present confined to the highlands of Peru, Venezuela and Columbia but capable of doing great harm to our potatoes if it arrives here. Nor have we ourselves been guiltless ; in the early days America got from us the Gypsy moth, Brown-tail moth, European corn borer, pea thrips and a variety of others which are now pests. In the case of the fungi the newcomer may be an old form that has suddenly produced a more virulent mutant, like the Verticillum Wilt that for years had lived harmlessly in Kentish hop gardens and then suddenly in 1924 in a hop garden at Penshurst, assumed a destructive habit, spread and became a bad pest. Fortunately two of Salmon's new varieties have been proved by Keyworth to be resistant. The Downy Mildew of hops formerly known only in Japan suddenly appeared in the Wye hop garden in 1920 and within ten years had spread into all the hop growing districts. Instances could be multiplied. Kenya has already acquired a serious canker of Macrocarpa that threatens to put this useful tree out of cultivation. It is caused by a fungus *Monochaetia uniformis* previously known only as a herbarium specimen in Kew, Pretoria and California. Kenya's valuable pyrethrum crop suffers severely from a bud disease caused by *Ramularia bellumensis* known only as a comparatively harmless fungus in glass houses in Cheshunt and in Italy.

Insects do not appear so readily to change their habits and become pests : the classical example is, of course, the Colorado beetle which lived blamelessly in Western America till the 1860's when the first settlers introduced the potato. In our own country a Capsid that used to feed on willows suddenly took to apples and became a major pest.

The Blister Blight of tea (*Exobasidium vexans*) has now appeared in Ceylon : if it cannot be checked it may seriously reduce the crop and the vigour of the bushes. And so one could go on. Sometimes a new crop has been introduced bringing a new pest like the sugar beet eel worm or a new plant that forms an alternate host : like the barberry which was introduced into North America. An introduced crop may suffer from an insect harboured by a native crop which therefore may have to be sacrificed ; in the Sudan the popular vegetable Lady's Fingers harbours a minute white fly that damages the long staple cotton in the Gezira and so the vegetable is prescribed in that region. Happily, the mite does not effect the American cotton grown in the non-irrigated regions : people can, therefore, eat Lady's Fingers there. A new insect coming in may displace another that has been keeping down a pest and so in a kind of third party relationship it may enable the pest to damage the crop. In Zanzibar an indigenous ant, *Cecophylia longinoda* preys upon a Coreid insect which is liable to damage the young female flowers of the coconut and so of course reduce the yield, and in the area where it is active damage is only slight. But an exotic ant, *Anaplolepis longipes* has in certain districts driven out Cecophylia; it does not prey upon the Coreid, which can therefore multiply and the yield of coconut falls. Control of Anaplolepis could no doubt be effected.

A complicated problem would arise, however, if as seems possible, Sudden-Death of cloves in Zanzibar should be a virus disease transmitted by the Scab insect *Saisetia*. For this insect is attended by the ant *Cecophylia longinoda* and by it carried from tree to tree and protected from parasites and predators. In that case should Cecophylla be spared in order to save the coconuts or destroyed in the hope of saving the cloves ?

Changes in agricultural practice such as have taken place in this country in recent years may alter the balance of insect populations and bring one or other into prominence or cause it to change its habits, for example, the crowding of potatoes caused the eelworm to multiply. Even a great agricultural triumph like the 500 mile northward extension of the Corn belt in the upper Mississippi Valley through the introduction of an earlier ripening maize, may raise new difficulties : the stalks and stubbles proved admirable for the over-wintering of scab or head blight of wheat and barley and great losses of those crops have followed.[1] The modern tendency to larger scale cultivation of particular crops favours accumulation of their pests. Wigglesworth has pointed out that our small fields, considerable range of crops, our hedgerows and road side verges encourage a variety of insect predators and parasites: as we smooth out the variety in accordance with modern tendencies to uniformity so we increase the risk of insect pests. North America, whose large scale methods we are sometimes urged to follow, suffers more from insect pests than we do. The very care taken to control them has, in some cases at least, been accompanied by increases because their natural enemies and predators had been destroyed. A. D. Pickett[2] states that six or even ten sprayings are now required in the orchards of Nova Scotia to get good quality fruits, whereas only two or three were needed 50 years ago. Dr. V. B. Wigglesworth discussed this whole question in an address at the British Association in 1950 and emphasised the need for fuller study of the effects of insecticides on the whole insect population, and for developing biological methods of maintaining a proper balance in the insect population. Chemical methods alone in his view will not suffice : " the problem of pests in general," he says, " gets worse ......new machinery and new chemicals are developed and we are carried from crisis to crisis always hoping that the newest chemical or the newest technique will provide the final answer." Other entomologists, *e.g.*, R. A. E. Galley, C.B. Williams and others take a similar view and put the emphasis on the population rather than on the individual species. Undoubtedly, the problems would become much simpler if it were possible to maintain the insect population in a condition where mutual interactions prevented any one species from increasing to the dimensions of a pest. Fortunately, a strong East Malling team in association with Dr. Wigglesworth's Unit of Insect Physiology is now studying the general problem from a wide point of view. The purpose is not so much to search for remedies for particular pests and diseases—important though these are—as to study the interrelation of the organism concerned with the host plant. This indeed has long been East Malling's attitude, developing from the experimental approach of Hatton and his co-workers in the early days. Examples may be found in the work of Massee, Blair, Collyer, Austin and others on the Fruit Tree Red Spider Mite, in Wormald's and Cross's work on bacterial Canker, in Moore's on Brown Rot of Apples and Plums, and in Dicker's on Fruit Aphids. The present studies deal with the insect population of the orchard as a whole, especially the beneficial insects. Instead of confining the work to the pest and the insectcide, plant protection is recognised as requiring the widest ecological studies to determine the probable ultimate effects of the treatments adopted.

I need not enlarge on this view ; Dr. Holmes is discussing it. I agree entirely that one of our greatest needs now is for more fundamental knowledge.

The Increasing Struggle for Higher Output

The problem is really widespread. The conditions of our time require high levels of output of food from the land, and in attaining these we are perpetually disturbing Nature's balances and coming into unexpected difficulties. The plant

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[1] C. E. Stakman, *loc. cit.*

[2] Canadian Entomologist 1949, Vol. 81. pp. 1.

breeder's latest successes may succumb to a new strain of the fungus he thought he had defeated. The agronomist may find his new intensive methods lead to soil deterioration or even erosion. An irrigation scheme may be a triumph of modern engineering, but it may speedily be followed by water logging, salting and other soil troubles. It is as true today as when Horace wrote : " You may expel Nature with a pitch fork but she always comes back again." Our problems, like Einstein's Universe are perpetually expanding. Does this mean that we must give up the struggle ? Not in the least. We must go on seeking first to learn all we can about the plant in health and disease, studying in the fullest extent the relations of these various organisms one to another ; remembering always that any interference with one group of organisms may upset some delicate balance and lead to quite unexpected results. The plant protector started as a priest armed with incantations, a sheep and a reddish sucking puppy for sacrifice : he has developed into a modern scientist equipped with well founded knowledge and efficient appliances both of which are constantly widening and improving. Close, careful observation, clear thinking and a broad minded approach to his problems still remain his greatest assets in his work.