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SESSION I

Chairman: Mr. F.W. Morris

OPENING ADDRESS

Sir Frederick Bawden
President of the British Insecticide and Fungicide Council

Mr. Chairman, Ladies and Gentlemen,

I add my welcome to the Chairman's and express the hope that this our Fourth Conference will be both useful and enjoyable. That these Conferences fill a need and are appreciated seems evident enough, for the numbers attending increase each time and this year there are almost 700 with more than 200 from overseas.

Perhaps the most useful thing I can do in these introductory remarks is to comment on our programme. Those of you who have already looked at it will have noted the most obvious innovation, which is that we are having concurrent sessions. The Conference has always included many specialist papers and these increase but, of course, by definition, cannot in their technical detail appeal to all the many delegates attending this Conference whose interests are necessarily diverse. It is to cater for the specialists and to meet the general needs that this year we have concurrent meetings dealing with different subjects.

The Conference Committee has taken as its main theme the pest and disease problems that accompany the intensification of agriculture and horticulture and how best to overcome them. With world populations growing rapidly and with land being increasingly taken from food production for other purposes, it seems inevitable that agriculture and horticulture must become still more intensive, and to increase yields and quality of produce demands still better control of pests and diseases. Hence we are considering not only the use of pesticides but how these can best be combined with other measures that may limit losses from pests and diseases.

Our first session launches this theme, what is now widely called integrated control and we are fortunate that Professor Ray Smith was able to accept our invitation to give the opening paper and tell us what is being done in California to combine various methods of limiting crop losses. Until the era of modern patent insecticides, control rested on biological factors, such things as the use of resistant varieties and cultural or hygienic practices that lessened the attack or losses caused by pests. With the great success of the insecticides produced since the Second World War, it seemed these might alone answer our problems and for a while other methods of control tended to be forgotten. It is now only right and proper to consider our whole armoury and see whether the effectiveness of pesticides can be increased by combining them with other measures and whether they could avoid the unwanted effects that they sometimes cause.

Modern pesticides are powerful tools and, like all powerful tools, require careful use to ensure they do their job thoroughly and safely. Mindful of their potential for harming organisms other than the pests at which they are aimed, in addition to our session on integrated control, which may show us how to control pests effectively with smaller amounts of pesticides, we also have a session considering effects of pesticides on wild life.

Other sessions deal with the soil-borne pests and diseases of cereals, which are becoming increasingly important as cereal growing becomes more intensive. What the current losses are from these pests and diseases of cereals in the United Kingdom, I cannot estimate, but I do know from experiments we have done from Rothamsted - less so at Rothamsted itself than elsewhere because our heavy land there is less conducive to many soil-borne pests and diseases than light land - that after partially sterilising land where cereals have been grown often, yields have been twice those on untreated land, whatever the fertilizer dressing. With long crop rotations no longer practised on many farms, the soil-borne pests and diseases, not only of cereals, but of other crops that are grown frequently, will increase unless we have better methods than current ones of attacking the pathogens.

But it is not only to control the soil-borne diseases of cereals that we urgently need better pesticides than we have today, because the control of the air-borne diseases of cereals rests largely on the use of resistant varieties, and for how long these will retain their resistance is uncertain. There is a great prize for the chemical industry and great rewards for agriculture from pesticides to control either soil-borne or air-borne diseases of cereals, but preferably both.

In countries where weeds are now largely controlled by herbicides, the cost of treatment, if something could be found that is effective when sprayed on the crop with the herbicide, would be only the cost of the chemical. Soil sterilization, which of course controls the soil-borne pests and diseases, is too expensive to be used for crops such as cereals. The glass-house industry, where monoculture has long been practised, keeps going only by regular soil disinfestation. There is no reason to think that soil gets any sicker under glass than it will in the open when one type of crop is grown with the same frequency as under glass, and it seems only reasonable to think that to get full crops out-of-doors with intensive farming they will have to be treated in ways comparable to those used under glass. Already this is done for some crops that produce a large return per acre and where labour is dear. I was impressed in Hawaii to see a machine that was covering two acres an hour. It was not only fumigating the soil, but was injecting liquid ammonia fertilizer, distributing granular phosphate and potash fertilizers and was paying out three rolls of black polythene carrying marked positions where the pineapples would be planted. The only thing wrong was that the machine cost 84,000 dollars, which is a bit expensive to use on land for growing wheat or barley. However, the necessity to kill soil-borne pests and diseases is going to become necessary with such crops if present agricultural trends continue.

Another crop that is likely to be grown increasingly by specialist growers and on a decreasing acreage is the potato, and we have a session dealing with tuber-borne pests and diseases. It is evident that here again we need better fungicides than current ones to rid tubers of the fungi with which they are now only too commonly infected. The potato certification story in this country has gone through rather a curious cycle. It started to prevent, control or eradicate, I do not know what word should rightly be used, potato wart disease by ensuring that only immune varieties were planted on infested land. Having succeeded in its task, a magnificent example of integrated control, although the phrase was then unknown, the Certification Scheme was adapted to, and became immensely valuable for, the control of potato virus diseases. Here again the Certification Scheme was extremely successful in as much as, in the United Kingdom, the effects of aphid-borne viruses are no longer to be measured in terms of crop loss, but in the extra cost of buying certified seed or, recently, the cost of insecticides to check the aphids responsible for their spread. But meanwhile other tuber-borne fungi than wart have become increasingly common and are now troublesome both to growers of seed and ware potatoes.

Ladies and gentlemen, I do not propose to stand between you and the technical sessions any longer; nor to comment further on the programme the Committee has prepared for you, but leave you to savour it in the hope that you will find both the main theme of our Conference and the specialist papers scientifically rewarding.

Before I sit down, I regret having to make the sad announcement that Mr. W. C. Moore died on Saturday. Most of you here will have known him and he was probably a personal friend of many of you, as he was of mine. First as Mycologist to and later as Director of the Ministry of Agriculture Plant Pathology Laboratory at

Harpenden, he did much in this country to develop the better use of insecticides and fungicides. He played a large part in developing the Approval Scheme, and was active in our early Conferences. As well as paying my inadequate tribute to Mr. Moore as an eminent pathologist, friend and colleague, I would ask you, ladies and gentlemen, to rise and stand.
(The Conference stood as a mark of respect).

RECENT DEVELOPMENTS IN INTEGRATED CONTROL

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Summary Integrated control derives its uniqueness of approach from its emphasis on the fullest practical utilization of the existing mortality and suppressive factors of the agro-ecosystem. It has two fundamental principles to guide it: a) Consider the agro-ecosystem; b) Utilize economic levels. Integrated control programs require a high level of scientific background. At least a minimum level of information is usually needed on the following points: a) The general biology, distribution and behavior of the key pests; b) An approximation of the pest population levels that can be tolerated without significant crop loss; c) A rough evaluation of the times and places of occurrence, and the significance of the major predators, parasites, and pathogens present; d) Information on the impact of the use of pesticides on natural enemies. Chemicals are, and probably will remain, our main tool in the management of pest populations. Partial controls gained from the action of natural enemies are an essential part of integrated control.

DEFINITIONS OF INTEGRATED CONTROL

Confusion and differences of opinion concerning the scope of integrated control make it appropriate here to discuss briefly the meaning of the term. Integrated control was proposed eight years ago by Stern and his colleagues for the integration of chemical and biological methods of control (Stern, et al., 1959). To understand the full scope of their definition, it should be realized that these authors considered biological control to include the full action of both introduced and native natural enemies. Their emphasis in the definition on chemical and biological control procedures was to underline the fact that these two approaches could be integrated. However, in practice we have come to learn that the integration of these two important methods of control should mean the integration of all crop protection procedures.

At a recent meeting of the Panel of Experts on Integrated Pest Control of the Food and Agriculture Organization in Rome, integrated control was defined as follows: "It is a pest management system that in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible and maintains the pest populations at levels below those causing economic injury." In its restricted sense, integrated control refers to the management of single pest species on specific crops or in particular places. In a more general sense, it applies to the coordinated management of all pest populations existing in the agricultural or forest environment. Integrated control is not simply the juxtaposition or superimposition of two control techniques, such as chemical and biological controls, but rather it is the integration of all suitable management techniques with the natural regulating and limiting elements of the environment. It is from this emphasis on the fullest practical utilization of the existing mortality and suppressive factors that integrated control derives its uniqueness of approach. Hence, it is not synonymous with ecological control although ecological principles are its foundation, nor is it simply the integration of man's total efforts in the area of pest control.

Integrated control is distinct because of its emphasis on the utilization of the innate mortality and suppressive factors existing in the agro-ecosystem. It should be emphasized that these mortality and suppressive factors of environment are not synonymous with biological control even when defined broadly. The scope intended here is more extensive. In addition to the mortality or suppression resulting from the activity of parasites, predators, and pathogens, the effects of certain abiotic factors and competition are included in specific cases, the effects of weather, the suppressive consequences of resistant qualities in plants, mortality or decreased reproductive capacity resulting from competition for a limited diet may be important.

In practice, full integration may have three components. First, there should be an integration of man's control procedures so that any conflicting aspects, such as the deleterious impact of a chemical treatment on a parasite-predator complex, are reduced or eliminated. Secondly, there should be an integration of the control measures taken against the several pests occurring together on a crop. This form of integration should not be limited to the control of insects but should also include suppression of diseases and other crop pests. Finally, and most importantly, there should be an integration of man's purposeful control activities with the mortality and suppressive influences of the abiotic and biotic environment. These three levels of integration fully justify the term "integrated control."

BASIC PRINCIPLES OF INTEGRATED CONTROL

In the light of this discussion of the definition of integrated control, there are to my mind but two fundamental principles involved. All other so-called principles and guidelines are subsidiary or corollary to these two. The first of these principles can be simply stated "Consider the agro-ecosystem." In other words, pest control should be developed and applied in the context of the total environment. Pest populations are to be managed in such a manner that the existing limiting and regulatory factors are exploited to the fullest extent possible and without disturbance to the regulation or control of other pests. This first principle defines the underlying philosophy in our approach to the development of integrated control systems.

The second principle is "Utilize economic injury levels." The determination of the levels of tolerable pest damage in agricultural croplands and in forests is an essential prerequisite to the development of integrated control programs. Additional or supplementary mortality or regulatory elements are introduced into the environment at the appropriate times to maintain the pest populations at levels below those causing economic injury. These economic levels should be determined both in terms of the foreseeable crop loss and the economics of crop production and marketing. While the utilization of economic injury levels is critical for integrated control it should, in fact, be a part of any pest management system, for the definition of economic injury levels defines the goal of pest control procedures.

Although economic injury levels have long been considered to be of importance in determining the needs for pest control, they take on added significance in integrated control. This is mainly related to the importance of maintaining subeconomic levels of the pests to provide for the continuity of natural enemies.

There is not time here to elaborate the problems associated with the establishment of economic levels or their utilization in integrated control. For more details, I refer you to the series of papers given last month at the FAO Symposium on Crop Losses (FAO,1967).

GUIDE LINES FOR INTEGRATED CONTROL

From these two basic principles of integrated control and from related principles of ecology and crop protection, a number of guide lines can be established for crop protection procedure. These guidelines vary in their importance; some are only applicable to certain crop protection situations, others are applicable more generally. The following nine guidelines for integrated control were elaborated in a somewhat different form earlier this year by the FAO Panel of Experts on Integrated Pest control. The first three apply to the full development of integrated control in any situation and the others have been shown to have application in more specialized cases.

1. Identify the environmental factors that permit a species to achieve pest status; and then, if possible, manipulate these factors in a plan of integration to keep the pest from causing economic damage. From among the numerous factors in an agro-ecosystem contributing to variations in pest abundance, there are usually only one or a very few that account for most of the variation. If such key factors and other "releasing elements" can be identified then we have a very powerful tool to utilize in pest management.

2. Every effort should be made to reduce the level of effort placed on pest management and the annual cost of crop protection. This concept can be illustrated by starting with an example "classical biological control" which results in perfect control. This ideal situation, which is of course seldom realized, has a "once only" cost of development and introduction and no subsequent management effort or costs. The development and introduction of a resistant plant variety has similar cost and effort relationships. In most other pest control situations, there are continuing costs and the goal is to reduce the annual input of effort and money. In attempting to achieve this, the efficacy and efficiency of the control procedures should be considered, not only in relation to the direct cost of mortality achieved and crop protected, but also with respect to such background elements as stage of plant development, the agricultural production system, plant host density, and pest abundance.

3. Flexibility in crop protection procedures should be maintained to allow for the variations in time and space and to permit an adjustment to the inevitable evolution of crop production within the agro-ecosystem. There is so much variation from field to field and from crop area to crop area, and there are so many changes in crop production, for example changes in variety or cultural practices, that we must have flexible procedures that can adjust to change.

4. The establishment of integrated control programs in ecologically disrupted areas (for example, large areas devoted to monocultures or those treated heavily with broad-spectrum insecticides) must often be done gradually with close coordination of research on both crop production and crop protection with the practical applications. As we begin to modify agro-ecosystems by changing the kinds of chemicals being used or by introducing new natural enemies, we may permit an increase in the influence of other mortality and suppressive aspects in the population dynamics of a pest. For example, in California the natural enemies that were most important in the early phases of integrated control programs for the spotted alfalfa aphid, *Therioaphis trifoli*, are not the same as the ones which are most effective at the present time. As the populations shifted to lower general levels of abundance, there has been a change in the relative importance of the natural enemies. In the first few years, a variety of native coccinellid beetles became superabundant. Of the three introduced parasites, a *Praon* species became abundant first--probably because of its ease of establishment and rapid spread. Today, a *Trioxys* is the dominant regulating species except in coastal areas. The coccinellids are still present and important but are back to more characteristic levels.

5. Primary sources or reservoirs of pest populations should be evaluated and managed carefully, especially when they are small in relation to the total infested area. Very often pests, concentrated on weed hosts or in otherwise restricted areas, are more susceptible to management than later when they have spread over large areas and to valuable crops. This is especially true for migratory populations. An outstanding example of this point is, of course, locust control, but the concept undoubtedly has far wider application in pest control.

6. Pest control procedures should be directed to affect only a limited portion of the agro-ecosystem; that is, they should be used selectively and have their greatest and, when possible, only impact on a target pest species. This is an ideal

goal; nevertheless, it should be an important guideline in the development of integrated control. As chemical pesticides are one of the most widely used and most effective means of manipulating pest populations we must look for selectivity in their use. I shall amplify this point a bit later in the discussion.

7. Parasites, predators and pathogens which have been determined to be of significance in the regulation or limitation of pest species should be augmented and fostered. An important point to be emphasized here is the inference that not all parasites, predators, and pathogens are of significance in pest control. There seems to be no a priori basis to establish the importance of a natural enemy (De Bach, 1964). We must have, in each case, careful studies to determine the effectiveness of natural enemies and what limits their effectiveness. With that information in hand, we can then utilize them efficiently and protect and augment them as appropriate.

8. Diversity in the agro-ecosystem tends in general to maintain stability and hence should be conserved. The complexity of the lovely British countryside as compared to that to which I am accustomed in the Central Valley of California, undoubtedly is of aid in maintaining the stability of insect populations in your agro-ecosystems. We have recently developed in California two practical examples utilizing ecological diversity. Strip cutting of alfalfa increases the diversity and stability of the agro-ecosystem and fosters a variety of natural enemies. The planting of blackberries in the vicinity of vineyards permits the successful overwintering of an important egg parasite of the grape leafhopper. However, the mere statement that diversity is important is not enough, we must delve into each situation, determine the complexities and how they operate and then manipulate them to our advantage.

9. Some surveillance of pests and ecological change must be maintained in the integrated control program to monitor the need for reestablishment or modification of control procedures.

ESTABLISHMENT OF INTEGRATED CONTROL

Most of the obstacles in the way of successful establishment of integrated control are common to the expansion or improvement of crop protection by any procedure. In each situation, the costs, hazards and problems involved with the proposed control system must be carefully considered in comparison with established or alternative systems. The essential prerequisites for the establishment of integrated control are adequate scientific knowledge, qualified personnel, and suitable administrative structures.

Scientific Background Integrated control programs in general must be established on the basis of a high level of scientific background (FAO, 1966). There must be at least a minimum level of information on the following points: (a) the general biology, distribution, and behavior of the key pests; (b) an approximation of the pest population levels that can be tolerated without significant crop loss; (c) a rough evaluation of the times and places of occurrence and the significance of the major predators, parasites, and pathogens; (d) information on the impact on natural enemies of the use of pesticides as well as other control measures.

This information will usually provide an analysis of the causes of pest status which can in turn be manipulated to minimize the importance of the pest. The belief that it takes too long to develop the necessary information and technology to meet current crop protection needs is not supported by the cases where integrated control has been established. Research results influence or modify the control procedures at a very early stage and subsequently all along the way towards full development. In some instances, it is also important to develop adequate surveillance or prognosis techniques to guide the control procedures. Not only changes in the pests themselves, but also changes in crop production may greatly modify the pest situation and require alterations in procedure.

Personnel There is a permanent need for trained personnel, especially in developing countries, at the research, surveillance, extension, and administrative levels of crop protection. In order to carry out integrated control at any reasonable level, it will be necessary to recruit and train large numbers of specialists and to provide considerable background information for others associated with crop protection. A variety of training devices will be needed to meet this requirement. The lack of trained personnel sensitive to the integrated control approach and capable of conducting the basic research needed on the population dynamics of pests and their interrelationships with other organisms and the environment, is a problem common to all countries and in a general way affects all biological research.

Administration Successful development of integrated control plans requires more than the acquisition of basic knowledge of the pest and control procedures. The programs also require an adequate administrative structure to carry out the program. This includes permanent staff to maintain a surveillance of the pest, supervise the control procedures, and educate the growers. These phases must be coordinated by an administration sympathetic to the long-range aspects of pest control. A strong and able administration knowledgeable of the importance of integrated control can greatly facilitate its development. For example, it can provide appropriate legislation to improve pesticides usage and invoke quarantine measures to prevent or delay introduction of pests. It can also overcome difficulties which are known to restrict the successful and practical implementation of control measures by either the crop protection specialists or the farmers.

IMPORTANCE OF CHEMICALS

While the broad integrated control approach attempts to employ non-chemical control procedures and utilize environmental suppressive elements to their fullest, it should be clearly understood that chemicals are, and probably will remain, our main tool in the management of pest populations especially as they approach economic levels. It is vitally important to integrated control programs that an adequate array of pesticides be available and that they be used to reduce threatening situations with little or no disruption within the agro-ecosystem. In other words, integrated control has not been developed as an alternative to the use of pesticides, but rather, it has been developed as a means for the more efficient and effective use of pesticides.

As we all know, there have been a number of unwanted side effects resulting from the use of pesticide chemicals. These have included the development of strains of pests resistant to the chemicals, the rapid resurgence of pest populations to new high levels following treatment, the contamination of the harvested crop or the environment with toxic residues, the destruction of non-target organisms, and the creation of new pests. This is not the place to document this story. The point in mentioning all this again is that the integrated control approach offers an opportunity to avoid some of these unwanted side effects.

While discussing the importance of chemicals in integrated control programs, it is essential to give special consideration to selectivity. If chemicals are to be used in a harmonious manner in the agro-ecosystem then we must have materials that are inherently selective or we must learn how to use them so that their effects are selective. All pesticides have some selectivity but the range in degree of selectivity is very great. Much effort has been expended in seeking materials with relatively high toxicity to invertebrates and low toxicity to mammals. We must also seek differential toxicity within the arthropods. We do not need the ultimate in specificity that would permit us to prescribe a specific chemical for each pest species. However, we do need materials that are specific for groups of pests such as aphids, locusts, lepidopterous larvae, weevils, and so forth. There are some indications that we can have some materials with such specificity and still have them economically feasible from the viewpoint of the chemical industry.

Another point to keep in mind in seeking this specificity is that as we increase dosages to high levels there is a tendency to lose specificity. In the extreme case, at very high dosages there is no specificity. Under integrated control systems, often the population dynamics of the situation or the pest abundance crop damage relationship is such, that we do not need to have high percentage mortality. Instead of seeking 95% mortality or higher, we may be satisfied or even happier with a kill of 75% or even much lower. Under such circumstances, the dosage of pesticide needed for the low percent mortality permits the desired selective action. I am afraid that the current screening procedures for new pesticides have passed by many compounds of great potential value for crop protection because of the emphasis on high mortality.

The development of new highly specific pesticides will undoubtedly come very slowly. In the meantime, we shall have to make the best use of those chemicals now available. In this regard, we have not fully utilized the selectivity available through the modification of dosages, formulations, times of application, methods of application and other techniques. Over the years, economic entomologists have developed a wide array of procedures to increase the percent mortality to the target pest species. These same techniques should now be explored to provide a differential mortality between the target pest and the non-target organisms. We do not need "perfect selectivity" (an all or none situation) rather it is more desirable to have a differential kill that leaves the balance in favor of the beneficial forms.

Finally a few words about the costs for the development of new pesticides and prospects for the chemical industry to recover these costs. The strictures that now surround the development of pesticides are such that the costs of development are very high and it is likely that the costs will continue to rise. Consequently, it is unlikely that the chemical industry can afford to develop independently the types of materials I have described above unless the potential markets are either very large or stable over a period of years. This means that interest of the industry becomes, of economic necessity, focused on the problems associated with the production of a few agricultural commodities. What then happens to the problems on commodities grown in less than carload lots? e.g. passion fruits, macadamia nuts, or horseradish. There are today a number of chemicals important (or vital) to an agricultural industry, which are used in very small amounts (a few drums taking care of the entire agricultural commodity for a year). These cannot be priced reasonably to bring an appropriate return on the cost of manufacture let alone the cost of development (Price Jones, 1966, 1967). Yet our society needs these materials. With the development of chemical attractants, repellents, the selective materials I ask for, and other specialized materials, it seems that more low-use materials will be needed. If it is not economically feasible for the private chemical industry to develop, manufacture, stock-pile, and distribute them, then other means will develop depending on the requirements and understanding of society. By society, I have in mind not only the general public, but also crop protection specialists, members of the chemical industry, regulatory officers, legislators, and farmers.

BIOLOGICAL CONTROL AGENTS

What can we expect of parasites, predators, and pathogens in integrated control systems? First, on the negative side, we cannot expect perfect control of established pests except in rather rare instances (De Bach, 1964). By "perfect control" I mean that the pest populations are kept below the economic levels at all times. The fundamental nature of the action of parasites, predators, and pathogens is such that we can expect only partial control. In those situations where natural enemies are operating effectively, the pest populations are usually maintained below economic levels only part of the time; at other times, and for a variety of reasons, they rise or threaten to rise to economic levels. It is these "partial controls" that are so important in integrated control programs and which must be augmented or supplemented by application of pesticides or by other means (Smith and van den Bosch, 1967).

In this discussion of the partial effectiveness of natural enemies in controlling most of our major pests, we must not forget that in most agro-ecosystems, the parasites, predators, and pathogens are key elements in maintaining a large variety of potential pests continuously below economic levels. Again it is the intent of integrated control procedures to manipulate the key pest species in such a manner that the potential pest populations are not released to pest status.

Wherever possible, appropriate efforts should be made to increase the complement of natural enemies associated with pest species. This is, of course, most appropriate for introduced pest species that have no effective natural enemies. Introductions of parasites and predators often results in unsuccessful establishment or at best only a partial control of the pest species. Again, the integrated control approach offers a means for the utilization of these partial successes. Either through the use of appropriate pesticides or modification of the agricultural environment a full control can be obtained.

Many, although not all, integrated control developments have occurred in south temperate or subtropical regions. In the agricultural areas of these regions, it is possible that the biological control agents have some advantage because of the relative stability of the general environment as compared to more northern areas. Nevertheless, in north temperate areas, natural enemies do occur and are effective at times (Messenger, 1965). The severity of the mid-winter break and the vagaries of spring weather often disrupt the intimate relation between populations of the natural enemies and of the pests. Again it is for these "short-circuited" situations that integrated control procedures can be most effective.

INTERNATIONAL DEVELOPMENTS

Throughout the world the integrated control concept has rapidly taken hold with those considering the future development of pest control. Perhaps the greatest impetus to this spread has been reaction to difficulties associated with unilateral use of pesticides -- particularly the development of resistance strains. As to be expected the actual implementation of integrated control systems has come more slowly.

In the fall of 1965, FAO held in Rome a well attended Symposium on Integrated Pest Control (FAO, 1966). Papers presented at that symposium have now been published and widely distributed. As another follow-up to this Symposium, the Director-General of FAO has appointed a "panel of experts" to advise FAO in the area of integrated control. A small portion of this panel met this fall and has made a series of recommendations to the Director-General. It would now appear that FAO will have an expanding interest in integrated control with respect to all its crop protection activities. This interest will probably take the form of educational publications, training programs and demonstration projects. The details of the early phases of the program are still being developed.

CONCLUSION

Finally in closing, I would like to emphasize that integrated control should not be considered as having been derived from sophisticated scientific agriculture in California, Nova Scotia, The Netherlands, or elsewhere. But rather that it derives from basic principles of ecology. These fundamental principles apply to man's manipulation of his agro-ecosystems without regard to the political and social structure of the country. The use of the land is an ecological operation. Although man's concepts of the land and its uses may be modified by religious or political belief, it is still fundamentally an ecological relationship involving man and his environment; hence we should turn to the ecologists for assistance. Man, if he is to survive on this planet, must do many things. High on the list, of course, are the control of human populations and the avoidance of contamination of the environment. But also man must have food. At least for the immediate future these food sources will come from the sun's energy and man's manipulation of his agro-ecosystems to trap and store this energy. Food is an essential requisite for the future and man's existence is limited by it. Through proper management of our agro-ecosystems, this food can be provided and at the same time we can preserve some of the higher qualities of life on this planet and a richness of the environment. It is my firm belief that this goal can be attained and that the integrated control approach will make a significant contribution to the achievement.

Acknowledgment

Many of the thoughts expressed above are the results of extended conversations with my colleagues on the FAO Panel of Experts on Integrated Pest Control and in the Pest Management Group at Berkeley. To them I extend my sincere thanks and appreciation for their valuable counsel.

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APHID-BORNE VIRUSES OF SUGAR BEET: A RETROSPECTIVE EXERCISE IN INTEGRATED CONTROL

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INTRODUCTION

The principles of control of aphid-borne viruses in sugar beet in Great Britain have been described at previous conferences (Hull 1961, 1965). They are based on crop hygiene, cultural practices and insecticidal treatment. My task on this occasion is to bring developments up to date and put them in the context of this symposium.

Seed Crops

The spread of yellows from seed crops to young beet crops was greatly decreased by the contract made in 1951 between the British Sugar Corporation, the seed firms and the growers, which defines the control measures to be taken in seed crops and ensures that only stecklings certified as healthy are grown-on to produce seed. Beet crops in the main seed growing area of south Lincolnshire were regularly crippled with yellows, but since 1951 they have been relatively free from virus diseases and more productive.

Recently methods of seed growing have been developed which resemble the growing of winter wheat. Hand work has largely been eliminated so the crop can be grown in areas where hand labour is not generally available away from the main sugar beet areas in eastern England. In 1967 almost a quarter of the seed crop acreage was grown in the central and southern counties of England. There seed crops are subject to less risk of yellows infection than in the main root growing areas, and adequate control is achieved in them with menazon seed treatment followed by routine insecticidal sprays. This development might well in time solve the problem of disease spreading between seed crops and root crops in England. To a great extent the change has been stimulated by the need for disease control.

Clamped mangolds

Clamped mangolds remain an obvious local source from which aphids and yellows spread to root crops in the spring, but mangold growing has declined to such an extent that clamps now have a smaller influence on yellows incidence. In 1966 only 40,000 acres of mangolds were grown, compared with 100,000 in 1960 and 300,000 in 1945. Propaganda to encourage removing the leaves from mangolds before storing them has helped to decrease the number of clamps which are heavily infested with aphids.

Other sources of infection such as ground keeping beets, wild beet, weeds and chenopodiaceous garden crops can be tackled when their influence is obvious in an area, but will always be with us. This means that in favourable circumstances some plants in beet crops will inevitably be infected with yellows early. Then the beet crop itself, grown intensively in the areas around the factories, becomes the main source of infection. When this is so, the influence of methods of growing the crop on the spread of the disease become more important, as does the use of insecticide to control infestations of aphids on the crop.

Cultural practices

Practices which discourage the increase and spread of aphids in sugar beet crops are generally those which also favour vigorous growth and sugar yield in healthy crops.

Winged aphids choose young sugar beet rather than older ones. They begin to infest the crop towards the end of May, or more often during June, so the grower's aim is, by sowing early in a well prepared fertile seedbed, to get his crop as forward as possible before aphids arrive. Early sowing, even in the absence of yellows, favours sugar yield. In three years' experiments at Broom's Barn with crops relatively free from yellows, March sowings have yielded 19.1 tons/acre of sugar beet, mid-April sowings 17.5, and early May sowings 16.0 tons/acre. Throughout the country average sowing date has tended to get earlier. In favourable springs much beet is sown in March but still, on average since 1963, over 30% of the crop has been sown after the 20th April. There is obviously scope here for increasing the national yield.

The plant stand giving the greatest yield is that with 25,000 to 40,000 uniformly distributed plants per acre. The British Sugar Corporation are continually encouraging their growers to increase the present mean plant population of 25,000 plants/acre. Thin, gappy stands of plants encourage aphid infestation and favour their increase. Yellows is obviously more prevalent in parts of fields where the plant stand is irregular than where it is uniform.

Improved herbicides, monogerm seed and precision drills offer the prospect of growing sugar beet crops without hand labour, and possibly without cultivation after sowing. Looking to the future, crops may be "planted to a stand" and rows narrowed to 10 to 15 inches apart to overcome the risk of thin plant stands which might develop with conventional row widths of 20 inches. Our experience at Broom's Barn is that such a development might well result in denser stands of plants than used at present and this would discourage aphid infestation and spread of yellows. On the other hand, planting to a stand may hold dangers that the earliest aphid infested and yellows infected, and therefore stunted, plants will not be cut out in singling and so remain as a source of infection for the crop; systemic insecticide applied to the seed or soil would overcome this problem. That cultivation practices will change no one doubts. Which way they will go I will not attempt to forecast, but undoubtedly how they would affect behaviour of aphids and risk of yellows spreading will strongly influence what is adopted.

Variety

No sugar beet are immune to infection with yellows viruses, so change of varieties has not influenced yellows incidence. The variety Maris Vanguard has been selected for tolerance and, when infected, yields more than other varieties. Its use is recommended in areas where yellows regularly occurs.

Insecticides

Modern insecticides are valuable for restricting spread of viruses in sugar beet crops, but if winged aphids carrying beet viruses are numerous enough to infect all plants in a crop, then spraying the crop gives little or no benefit. This is often the situation in California where massive infestations of aphids invade young sugar beet sown amongst virus-infected overwintered crops, and insecticidal sprays fail to protect the beet from infection with yellows. We have escaped from this situation by hygiene measures. With fewer virus carrying aphids and with crops grown in as unfavourable a way as possible for aphids, spraying will decrease spread of yellows within the crop and increase yield. To this extent control by crop hygiene and by cultural measures interacts with control by insecticides and the measures are interdependant and integrated.

The problem in practice is which crops to spray and when. Some people consider that the risk of yield loss if yellows should spread justifies routine spraying each year. Of course, any grower is at liberty to spray his crop when he thinks spraying is appropriate, and some growers of large acreages of beet in yellows-prone areas will spray their crops as a routine before the foliage covers the ground. But advising spraying the 440,000 acreas of Britain's sugar beet is a different matter. The four reasons we prefer a warning scheme rather than to advise routine spraying are:-

(1) Cost: a widespread routine recommendation would result in much unprofitable spraying.

(2) Timing: the optimum time for spraying varies greatly for different years and areas.

(3) Confidence: after a grower has sprayed unnecessarily for a year or two he may ignore advice to spray in the year when it proves beneficial.

(4) Resistant aphids: frequent use of organo-phosphorus insecticides might hasten the development of resistant strains of aphids.

The criterion to justify spraying is a reasonable chance that yield will be increased enough to pay for the spray.

Since 1959, sugar factory agriculturists have been guided mainly by the fieldmen's counts of green aphids on sugar beet in deciding when to send spray warnings to growers. Infestations averaging one green aphid per 4 plants in May or June have been considered the danger level of infestation. Spray warning cards may go to individual growers with infested crops, to all in a small area, a fieldman's area, or the whole factory area. The agriculturist is influenced in his decision by his knowledge of yellows incidence in the past as well as by numerous environmental factors and background information he receives from Broom's Barn. Most growers depend on the warning and generally act on the advice given.

On average, spraying pays when the incidence of yellows on unsprayed plots exceeds 20% at the end of August. Table 1 summarises yellows incidence in the 400 to 440 thousand acres of Britain's sugar beet and the acreage sprayed with insecticide during the last decade. The incidence of yellows might well have been double each year had no crops been sprayed, but clearly spraying cannot be justified on many acres in most years.

Table 1

Yellows incidence and insecticide spraying in Sugar Beet in Great Britain

Year	Acres sprayed with aphicide (thousands)	Acres with more than 20% yellows at end of August (thousands)	Mean % of plants with yellows at end of August
1958	79	88	16.2
1959	318	162	23.7
1960	240	144	21.7
1961	391	189	27.0
1962	84	2	2.9
1963	80	1	2.8
1964	143	3	4.3
1965	110	14	7.2
1966	294	30	9.1
1967	300+	25	8.0

Spraying experiments between 1962 and 1966 show that the timing of spray warnings has been correct (Hull and Heathcote, 1967). Sprays applied at the time of the warning have decreased yellows incidence, on average, by 37%, whilst those two weeks earlier or 2 weeks later have decreased yellows incidence by 24% and 25% respectively.

A single spray gives the greatest increment of yield increase. In 44 trials between 1957 and 1960, the increase of sugar yield from a single spray averaged 15% and from two sprays 19%. Except on occasions when infestation of M. persicae is very persistent, the justification for a second spray is to control the later infestation with A. fabae.

The extensive observations and experiments on the sugar beet crop allow not only practice to be related to experimental results, but practice to be improved on the basis of recorded experience. We have analysed data on aphid infestations and yellows incidence collected by fieldmen between 1959 and 1966 for the spray warning scheme. There is no clear cut correlation between any of the factors examined and eventual yellows incidence, but the results help in deciding when to issue spray warnings; there is, and as far as I can see always will be, a good deal of uncertainty in forecasting the risk of yellows in any particular locality.

The pattern of aphid infestation and incidence of yellows is different, as would be expected, in different areas, but the 17 factory areas can conveniently be placed in four groups. Green aphids come earliest and are most numerous in the south east, categorised as Group I factory areas. We can compare the aphid counts at any time with those of previous years, for which the eventual yellows incidence is known. From this the agriculturist can judge what acreage is at risk, and from fieldmen's aphid counts and his knowledge of where yellows tends to be most prevalent he can ensure that appropriate spray warnings are issued.

In most years, the warnings gradually build up area by area over a few weeks. The question arises, when is a general warning justified for a whole factory area? Scatter diagrams relating yellows incidence with aphid infestation at a time when a general spray warning is likely to be appropriate, show what success we can expect. We take 20% yellows incidence to justify a general spray warning; even with the spraying which has been done in the years reviewed, 40% of the acreage of beet would have more than 20% of plants with yellows and would have its yield appreciably decreased. The results summarised in Table 2 give reasonably successful criteria for Group I, II and III factory areas. Widespread spraying for yellows control in all crops in the areas of Group IV factories is seldom justified.

Table 2

Chances of a general spray warning being justified based on data collected during 1959 - 1966

	Group I (South East)	Group II (S. Midland)	Group III (N. Midland)	Group IV (Northern)
Cumulative aphid total at which general warning issued	0.25 aphids in weeks 1-5	1.0 aphids in weeks 1-7	0.5 aphids in weeks 1-7	0.25 aphids in weeks 1-7
	No. of occasions for general warning			
Success				
None justified - none made	20	22	27	24
justified - made	9	7	9	4
Failure				
None justified - made	1	1	3	3
justified - none made	2	2	1	1

Insecticide Resistant Aphids

The experience in glasshouses that strains of resistant aphids develop where organo-phosphorus insecticides are regularly used has made us very conscious of the risk of this happening in the field. Although the susceptibility of clones of aphids collected in the field varies considerably, there is no evidence that the use of organo-phosphorus insecticides in England has resulted in resistant aphids on sugar beet crops (Needham and Dunning, 1965). Probably the selection pressure resulting from occasional use of insecticide on sugar beet is not great enough to have more than a transient effect on the susceptibility of the field population. Resistance seems to offer no urgent problem, but will have to be watched. Any extensive use of seed or soil treatment at the time of sowing might incur greater risk of producing a population resistant to sprays during the summer. Similarly, resistant strains might be selected by use of insecticides on overwintering populations so spraying of mangolds before clamping is not recommended.

Predators and parasites

If "integrated control" infers taking measures to increase the activity of predators and parasites of the pest, then those taken to control viruses in sugar beet have no claim to be "integrated". The approach has been the realistic one of judging success by how effectively treatments prevent the disease. In contrast, early experiments showed that spraying sugar beet with DDT tended to prolong aphid infestations and increase incidence of yellows so its use was discouraged and alternative treatments were developed against leaf-miner and other seedling pests which also control early infestations of aphids (Dunning and Winder, 1965).

Sugar beet are sprayed to control yellows when aphid infestations are starting and few predators are present. Aphid infestations do not build-up in sprayed crops more than in unsprayed ones; almost invariably numbers are greater in unsprayed than in sprayed crops. Towards the end of July infestations dwindle and are cleared up by natural forces in August.

It is unlikely that virus spread can be restricted effectively by predators of the vectors in an annual field crop such as sugar beet. Encouragement of predators and parasites means maintaining an aphid population for them to feed on, and if this is in the crop itself it will inevitably mean spread of viruses. A more effective approach would be to encourage predators and parasites at the overwintering sources of viruliferous aphids, but sugar beet growers have not consciously done this. Crops which have once been heavily infested with aphids generally do not get infested again. On the other hand, autumn sown crops may be colonised by few aphids, and if they survive the winter they increase rapidly in the following spring. This suggests that a biotic factor might have built up on the heavy infestation of aphids which is restricting their increase later. The subject would justify investigation.

Although my paper has produced little evidence of conscious "integration" of measures for controlling sugar beet viruses it has, I hope, shown that they are based on factual evidence and common sense, they are complementary and they appear to be cumulative. They have an ecological basis. Four interacting entities are involved - the crop, the pest, the predator and parasites, and insecticides. The control measures we advocate manipulate the crop, the pest and the insecticide to give the crop the best chance and discourage the pest. The result is a productive crop, and when a grower produces a large crop he is called a good farmer. Integrated control is another name for that part of the art of good farming which science has so far defined.

The grower's problems and actions are influenced by his physical environment, his neighbours, the scientific advice made available to him and by the organisation in which he is operating. Attempts to control sugar beet yellows might have been very different had the crop not been organised by the British Sugar Corporation. One man on an isolated island would have quite a different problem growing sugar beet and keeping it healthy than do the 24,000 farmers growing 400,000 acres of sugar beet in England. The efficacy of control measures, as well as the incidence of the pest, is dependent on the environment, and control measures must therefore be integrated with environmental factors as well as with the cultural operations to be successful.

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SOME PROBLEMS IN THE ECONOMIC INTEGRATION OF CROP LOSS CONTROL

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INTRODUCTION

Crop losses due to pests, diseases, weeds, low soil nutrients, and sometimes lack or over-abundance of water, can be lessened if full use is made of modern farm techniques; but these may be applied to excess, leading to over-treatment and smaller cash returns. It has been suggested that some soil insecticides and seed dressings have been used excessively (Potter, Strickland and Bardner, 1965; Strickland, Bardner and Waines, 1962). Questions have been raised about over-use of cereal herbicides (Evans, 1966), and Large (1958) commented on the economically marginal returns from potato blight control in eastern England. Potato growers are also over-generous with N and K fertilisers (Boyd and Dermott, 1967). Clearly, there are cases where the input is higher than is needed to get a good crop response. Input does not only refer to the cost of a chemical and its application, and Professor Smith's Californian school has led in suggesting integrated pest control techniques which lessen dependence on chemicals and increase the chances that other controlling factors will work for little or no monetary cost. Other workers have studied the long-term implications of contrasted controls (Watt, 1963), and Headley and Lewis (1967) have discussed the data needed before sensible control policies can be devised. They underlined the importance of external costs in pest control, and emphasised that a given producer's financial interests may be best served by applying more than the nationally optimal input of pesticides if he is not personally affected by the external costs. In this paper internal costs are taken to be the costs of the materials used in necessary pest control, and waste of resources on unnecessary treatments is included in external costs.

For some time we at Plant Pathology Laboratory have collected information on the effects of pests on crop yields, and on the use of pesticides. We also have some data on costs. To-day there is only time to present the data for one crop, and wheat has been chosen because its problems are perhaps less complicated than some crops, and because the information on some of its pests and parasites is reasonably complete and reliable. The data are for 1960 to 1964, and are mainly averages calculated from results obtained over several years. In a few cases data from a single year have been taken as representative of the situation throughout the five years. It is important to note that sampling and statistical errors are associated with each of the many pieces of information. It is difficult to get good estimates of what happens on farms, and when data from different sources are combined - as in this paper - the final conclusions may not be very accurate. But as they are based on objective data they are likely to be more accurate than conclusions based on subjective assessments or wishful thinking.

WHEAT PRODUCTION COSTS

Table 1 shows the cost of wheat production in England in 1964, and has been adapted from the survey done by Jackson and Sturrock (1966) in which sampling was roughly proportional to the wheat acreage per farm.

Table 1

Wheat Production Costs, £/Acre, from the National Wheat Survey of 282 Farms in England in 1964

Factor	Cost
Seed	2.9
Seed Dressing	0.2
Fertiliser and FYM	3.5
Herbicides	0.6
Miscellaneous	0.6
Total Variable Costs	7.8
Fixed Costs	19.5
Total Costs	27.3
Grain Sales	45.4
Gross Margin	37.6
Net Margin	18.1
(Value of Straw)	(2.6)
Acres Grown, England and Wales, 1964:	2,111,486
Mean Cwt/Acre (Official Yield):	31.3
Mean Cwt/Acre (Survey Estimate):	35.0

The "miscellaneous" variable cost includes occasional field treatments with insecticides, and a component for herbicide application costs. Treatments applied by Contract were included by Jackson and Sturrock under Fixed Costs (Machinery). The mean grain yield on the surveyed farms was nearly 4 cwt higher than the national average for 1964; few small growers were included, and more than half of the farms were in the high-yielding arable areas of eastern and south-eastern England. On average, pesticide input cost about £0.8 per acre, or about 10 per cent of the total variable costs. Grain sales averaged £1.29 per cwt, including guarantee payments, and in this paper a rounded value of £1.3 per cwt has been used to convert estimated yields to monetary terms. The corresponding market price for wheat was £1.06 per cwt.

PESTICIDE USE ON WHEAT

Table 2 shows the estimated acreages of wheat treated annually with fungicides, insecticides and herbicides in England and Wales in 1960 to 1964. The data have been rounded to the nearest thousand for clarity and to avoid a specious aura of accuracy.

Table 2

Estimated Wheat Acreages Treated with Pesticides, and the Approximate Per Acre and Total Costs

Cause of Damage	Estimated Acreages Treated	Estimated Costs, £: Per Acre	Total
	I. SEED DRESSINGS APPLIED AGAINST:		
Seed-borne diseases	1,945,000	0.1	195,000
Wireworms	901,000	0.1	90,000
Wheat bulb fly	292,000	0.4	117,000
	II. FIELD TREATMENTS AGAINST:		
Insects	68,000	1.9	129,000
Weeds	1,517,000	0.6	910,000

Five-year Mean Acreage Grown:	1,965,000
Five-year Mean Cwt Grain/Acre:	30.3
Average Annual Treatment Cost:	£1,441,000

In the seed dressing part of Table 2 an application cost of 10.5d. per acre has been included in the seed-borne disease control costs; the insecticidal dressings were all combined insecticide/organomercury dressings and the costings indicate the price of the insecticidal components only. The wireworm dressings were mostly BHC/organomercury, though in 1961 there was some use of aldrin/organomercury wireworm dressings. The wheat bulb fly dressings included heptachlor, aldrin, dieldrin, and 40 per cent BHC, formulations in the proportions indicated in an earlier paper, from which the insecticidal field treatments were also summarised (Strickland 1965), and their nature is indicated in Table 5. The acreages shown in Table 2 do not agree exactly with the acreages published in 1965, and the present estimates have been adjusted slightly in the light of more recent information. The herbicide data have been extracted from Woodford (1964) and imply that about 77 per cent of the wheat acreage was treated annually. Further information is given in Table 5. Averaged over the whole acreage, wheat growers spent about £0.73 per acre on pesticides in the early 1960's, mainly on herbicides and seed dressings. This compares with the estimate of £0.8 per acre from the 1964 National Wheat Survey.

EXTENT OF INFESTATIONS

Table 3 shows the acreages of wheat believed infested with various noxious organisms which have been controlled with pesticides. There are many other species which damage wheat, but which were not chemically controlled in the period under review. The wireworm and leatherjacket acreages have been taken from Potter, Strickland and Bardner (1965), and the wheat bulb fly data from the same source have been recalculated as severely infested acreages with autumn egg populations of more than 1 million per acre; moderately infested, with populations of 0.5 to 1.0 million eggs per acre, and slightly infested, with egg populations of less than 0.5 millions per acre. The "slight" leatherjacket figure has been bracketed since it is now doubtful whether larval populations of the order of 200,000 per acre cause yield loss in winter wheat; further, much of the wheat land is ploughed and broken down before crane-fly eggs have hatched (White, 1967).

Table 3

Estimated Acreages of Wheat Infested, 1960 to 1964

Cause of Damage	Intensity of Damage: Severe	Moderate	Slight
Wireworms	16,000	337,000	154,000
Wheat bulb fly	30,000	17,000	37,000
Leatherjackets	11,000	22,000	(107,000)
Weeds	76,000	182,000	576,000
Seed-borne diseases		(1,376,000)	

The weed figures in Table 3 have been derived from Evans (1966), Hughes (1966), and further data provided by Evans (in lit.) in 1967. The data were from trials done on commercial wheat crops. Substantial yield increases were obtained from weed control in 5 per cent of the trials; moderate increases were obtained in 12 per cent, and slight increases were obtained in 38 per cent (see Table 4). Yield losses were recorded on the sprayed plots in 45 per cent of the trials. The Table 3 estimates thus assume that only about 5 per cent of the national wheat acreage is severely infested with weeds which badly affect grain yield, about 12 per cent is infested to a lesser extent, and so on. Wheat is mainly grown in arable districts, and there is some evidence (Roberts, 1966) that weed seed populations were lower in arable soils in the 1960's than in the preceding 20 or 30 years. Roberts suggested that weed numbers may be only 2.5 to 4 per cent of the actual weed seed population at a given time, and his arable weed seed population counts of about 40 millions per acre agreed with Hughes' data on weed seedling populations of 1.0 to 1.3 millions per acre in winter and spring cereal crops. Much wheat is grown on old arable land in rotation with crops like potatoes and sugar beet, and Moffatt (1966) cited non-gramineous weed populations of the order of 0.5 million seedlings per acre in an arable trial at Rothamsted in 1963. In summary, Table 3 assumes that about 40 per cent of the wheat land in the early 1960's was infested with enough weeds to affect grain yield.

The estimate for seed-borne diseases is from Hewett's work (Hewett, 1965, 1966, 1967). He has kindly re-cast his data and the bracketed figure under "moderate" in Table 3 implies that, on average, 70 per cent of the seed wheat samples submitted to the Official Seed Testing Station at the National Institute of Agricultural Botany in 1959 to 1964 were infected with one or more of the pathogens named in his papers. There were large year-to-year variations, and in the wet year 1963 to 1964 about 93 per cent of the samples were infected with glume blotch and/or "snow mould"; in 1962 to 1963, when it was drier, only 51 per cent of the samples were infected. Seed infection within infected samples was higher (10 to 15 per cent) in the wet than in the dry year (1 to 2 per cent). Seed-borne diseases are widespread, and a light infection can become severe if the weather changes appropriately. Bunt seems to have been almost completely controlled by fungicidal seed dressings, and its recent incidence is too low to enter into the present calculations (Marshall, 1960).

YIELD INCREASES FROM CONTROL

Table 4 shows the approximate yield losses on untreated plots in experiments when infestations were controlled at an early stage on the treated plots. The insect data have been published in papers already cited, or in their reference lists. The weed control responses are based on 40 trials done on commercial wheat crops by the National Agricultural Advisory Service in 1965 and 1966, and some which have not yet been published were kindly made available by Mr. S. A. Evans. As already mentioned, positive yield responses were obtained in about half of these trials, and it is worth noting that the mean response of wheat to herbicides correctly applied at the Rothamsted trials in 1961 to 1965 was a drop in yield of 1.9 cwt of grain per acre (Moffatt, 1966).

Table 4

Experimentally Indicated Yield Losses if Infestations of Varying Severity are not Controlled

Cause of Damage	Likely per cent loss in grain yield if damage not controlled when infestations are potentially: Severe	Moderate	Slight
Wireworms	30	10	(3)
Wheat bulb fly	50	20	(5)
Leatherjackets	22	6	? (0)
Weeds	25	12	(5)
Seed-borne diseases	(Mean: (4); Range: (0 to 40))		

NOTE: The bracketed percentages are poorly determined. The disease figures are not strictly comparable with the others and are discussed in the text. All of the percentages relate to a mean yield of 30 cwt.

The disease loss in Table 4 is a mean grain infection percentage based on Hewett's published data and weighted to account for regional differences in wheat acreages, varieties grown, and the incidence of the pathogens he dealt with. This figure is not strictly comparable with the others in the Table since it is a measure of damage rather than of gross yield loss. The (o to 40 per cent) range of loss refers to estimates from disease assessment experiments done on the Continent and cited by Hewett. Mr. Hewett has pointed out (in lit.) that if bunt was not already controlled about 19 per cent of seed wheat would be infected with visible bunt balls, and a further 14 or 15 per cent would be infected heavily enough to make the samples unsuitable for seed. Without protection, 30 to 35 per cent of wheat seed might be unsuitable for sowing since the resulting crop would be discounted for milling: in the 1930's the discount was 3 per cent. Nowadays bunted wheat is not accepted for milling and would thus not rank for subsidy. Clearly, but for fungicidal seed dressing protection, the assumed 4 per cent seed-borne disease loss from infected grain could be much greater.

KINDS OF TREATMENTS AND ESTIMATED PER ACRE COSTS

Table 5 summarises the kinds and costs of treatments applied to wheat. The insecticide costs are based on Manufacturers' price lists for medium quantities in 1963/1964. The herbicide costs are based on the prices of 40 wheat herbicide formulations on the market in 1963/1964, and the means have been weighted for the estimated usage of straight MCPA and of mixtures during the period under review. Growers with severe weed problems are assumed to have applied the maximum recommended doses, those with moderate infestations the mean doses, and so on. Coincidentally, when the three mean herbicide costs are weighted with the estimated weed infested acreages in Table 3, the overall mean cost of herbicide treatment is almost £0.60 per acre, as found by Jackson and Sturrock in their 1964 farm survey. The herbicide cost assumptions in Table 5 are admittedly naive, and imply that few growers used very costly materials to treat specific weed problems; the assumptions are, however, consistent with the suggestion in Table 3 that only a small proportion of the wheat acreage appears to justify expensive treatments.

Table 5

Kinds of Treatments Applied to Control Infestations of Varying Severity, and Estimated £/Acre Costs of Materials

Cause of Damage	When Infestations Potentially: Severe Treatment	Cost	Moderate Treatment	Cost	Slight Treatment	Cost
Wireworms	O/C + SD	1.88	SD	0.10	SD	0.10
Wheat bulb fly	O/P or O/C + SD	2.18	SD	0.40	SD	0.40
Leatherjackets	O/C	1.78	O/C	1.78	? Nil	
Weeds	MCPA or Mixt.	0.87	MCPA, Mixt.	0.69	MCPA, Mixt.	0.53
Seed-borne Diseases	SD	0.10	SD	0.10	SD	0.10

NOTE: O/C = organochlorine field treatment; O/P = field treatment with an organophosphorus material; SD = seed dressing; Mixt. = herbicide mixture like dichlorprop + 2,4-D; 2,4-DP + MCPA; Mecoprop + fenoprop, etc.

The cost of applying seed dressings is usually included by Merchants in the cost of seed wheat. Apart from this, no account has been taken of application costs in Table 5. These are considered as external costs and are dealt with in Table 9.

ESTIMATED PER ACRE RETURNS FROM TREATMENTS

In Table 6 the gross savings and apparent net profits have been calculated from the treated acreages in Table 2, the infested acreages in Table 3, the yield responses in Table 4, and the materials costs in Table 5. To explain the calculations: wireworm control with dressed seed on 154,000 slightly infested acres at £0.10 per acre, plus wheat bulb fly control with dressed seed on 37,000 slightly infested acres, at £0.40 per acre, are assumed to have given yield increments of 0.9 and 1.5 cwt of grain per acre respectively, worth £1.2 and £2.0 per acre. When averaged over 191,000 acres estimated to have been needfully treated with insecticidal seed dressings to control "slight" pest infestations the overall per acre saving was approximately £1.4, which was obtained for a treatment cost of a little under £0.2, giving an apparent profit of £1.2 per acre.

Table 6

Estimated Savings (£/Acre) from the Chemicals Believed to have been Needfully Applied to Wheat, Assuming the Responses Shown in Table 4

Cause of Damage	Factor	When Infestations Potentially: Severe	Moderate	Slight
Insects	Gross Savings	15.2	4.0	1.4
	Cost of Materials	1.7	0.3	0.2
	Apparent Net Gain	13.5	3.7	1.2
Weeds	Gross Savings	9.7	5.8	1.9
	Cost of Materials	0.9	0.7	0.5
	Apparent Net Gain	8.8	5.1	1.4
Seed-borne diseases	Gross Savings		(1.8)	
	Cost of Materials		0.1	
	Apparent Net Gain		(1.7)	

NOTE: Estimations based on a mean yield of 30 cwt/acre worth £1.3/cwt to the grower.

It should be noted again that the seed-borne disease estimates in Table 6 may be under-stated, and the net profit from adequate seed treatment may well be nearer £4 than £2 per acre in the wetter wheat growing areas, even if no account is taken of bunt control.

CASH STATEMENT

Table 7 summarises the data in the monetary terms applicable in 1960 to 1964. The total cash return from the insecticides, fungicides and herbicides needfully applied to wheat was of the order of £8 million. The chemicals used in these treatments are estimated to have cost growers nearly £0.9 million, so the return less the cost of the materials, but including external costs, was of the order of £7 million per annum.

Table 7

Estimated Returns from Treatments Needfully Applied

Potential Infestation Level	From Pest Control: Acres Needfully Treated	From Pest Control: £ Return	From Weed Control: Acres Needfully Treated	From Weed Control: £ Return	From Disease Control: Acres Needfully Treated	From Disease Control: £ Return
Severe	57,000	867,000	76,000	737,000)		
Moderate	376,000	1,490,000	182,000	1,056,000)	1,376.000	2,477,000
Slight	191,000	259,000	576,000	1,094,000)		
Totals		2,616,000		2,887,000		2,477,000
Cost of Materials		248,000		497,000		138,000
Return less Materials Cost		2,368,000		2,390,000		2,339,000

"Needful treatment" implies that the grower succeeds in controlling an attack that would otherwise have lowered his grain yield as indicated in Table 4. Overspill treatments, applied unnecessarily, have not been included in Table 7. In sum, such treatments seems to have cost growers about £2.4 millions per annum in the years under discussion, and they are considered in Table 9 as external costs.

OTHER FACTORS WHICH CONTRIBUTE TO YIELD

Any attempt to integrate pest control in an economic sense must take account of the other factors which contribute to grain yield, and to the variable costs of production. Pesticides have mainly been used on wheat since about 1945, though it was not until the mid 1950's that they were applied on a substantial scale. It should therefore be possible to estimate an approximate overall return from pesticides by comparing yields in the 1940's with yields in the 1960's after allowing for the non-pesticide factors which were introduced between the two periods. In this connection Elliott (1962) examined the changes in national average wheat yields from 1941 to 1959, and subsequently (in lit.) to 1963. He suggested that varietal changes contributed about 4.1 cwt to the national yield, which was 19 cwt per acre in 1941 to 1947, and approximately 7 cwt was to be explained by "other factors". He did not analyse these: "Other factors which include the increased use of fertilizers, chemical weed control, better seed dressings and combine harvesters".

Lessells and Webber (1965; 1965 a) reported results from 134 trails to assess the N requirements of wheat. Their data suggested a mean response to 60 units of N of 8.8 cwt per acre for spring wheat and 6.1 cwt for winter wheat. The average dressing in 1962 was 55 units (Boyd, 1967), and an overall mean national response of 6.5 cwt seems reasonable. In 1941 to 1947 wheat received about 16 units of N per acre, and Crowther and Yates' Response Curve suggests that this gave about 2.5 cwt of grain per acre. Thus nationally the increased use of N fertilizers in 1960 to 1964 was probably responsible for about: (6.5 - 2.5) = 4.0 cwt per acre.

With P fertilizers Devine and Holmes (1964) suggested a 0.8 cwt response in spring wheat trials, but this was not statistically significant and they get negative responses in three-fifths of their loam and clay sites. Boyd (1967) noted that use of P is related to use of N, and showed the amounts used on commercial winter cereals. In the light of these findings a P contribution of about 0.5 cwt of grain per acre nationally seems reasonable. With K fertilizers Boyd and Frater (1966) showed a mean response of 1.1 to 1.2 cwt per acre in wheat on chalky soils in 24 trials done in 1956 to 1960. Dyke (1968) took the mean K response on old arable land at Rothamsted to be about 0.4 cwt per acre, and Boyd (1967) has questioned whether the general use of K is economic. For present purposes a mean response of about 0.6 cwt seems reasonable since much of the national wheat crop is grown on arable land rather than under the cut grass regimes which, as Dyke emphasised, may lead to K starvation.

The improved varieties grown in the 1960's often showed better responses to fertilizers than their wartime predecessors, and these interactions are considered to be included in the estimated overall response of 5.1 cwt of grain per acre from N, P and K.

The pest, disease and weed control aspects of Elliott's calculation can be estimated from the data in Tables 3 and 4. The named pests, seed-borne diseases, and weeds, potentially lessened production by about 9.8 per cent which was equivalent to nearly 3 cwt of grain per acre. However, the controls used in the field trials on which Table 4 was based were not completely efficient, and examples of the estimated efficiency of experimental and commercial field treatments have been given elsewhere (Strickland, 1966). Also, bunt has been left out of the calculations. Thus the full pest and disease control potential may have been nearer 4 cwt than 3 cwt per acre.

Elliott mentioned combine harvesters. Tests at Rothamsted in 1953 and 1954 showed a mean increase of 0.75 cwt per acre from combine harvesting compared with reaping and binding (Gardner, 1958). However, Catt's (1967) survey suggested a mean loss of approximately 0.66 cwt per acre on farms in the south-west, due mainly to bad adjustments and over-fast forward running speeds. Thus in practice growers may be losing most of their potential harvesting gains.

There are many other factors which can improve grain yields, like increased plough depth, earlier sowing and more timely operations made possible by better farm machinery, improved drainage, and rotational changes. There are few objective data on the extent to which these improvements were adopted by farmers in the early 1960's, and estimates of their effects cannot be included in the present calculations. It is, however, worth noting again the difference of 3.7 cwt between the 1964 Survey and Official grain yields: some of this may have arisen from improved practices used by the surveyed growers.

The national wheat yield in the early 1960's was officially 30.3 cwt per acre (Table 2). There may have been a tendency to under-estimate in good years and over-estimate in bad. Over a long enough run of years these errors cancel out, and it seems reasonable to take the official mean yield for 1941 to 1947 as a baseline for the time when wheat was produced without pesticides other than fungicidal seed dressings, the use of which was limited: in 1938 it was estimated that less than one-third of the cereals were sown with organomercury-dressed seed (Wakely and Mellor, 1938). So far as it has been possible to estimate them, the components of wheat yield in the early 1960's are shown in Table 8.

Table 8

Components of Wheat Yield Estimated for 1960 to 1964

Factor	Estimated Cwt/Acre	Percentage Contribution to Total
Baseline Yield, 1941 to 1947	19.0	61
Varieties, and Interactions	4.1	13
with Fertilizers	5.1	17
Pest, Disease and Weed Control	2.9	9
Totals:	31.1	100

The figure 31.1 cwt is reasonably close to the official 30.3 cwt, and closer to the mean official yield of 31 cwt in the arable counties where most pesticides have been used in recent years. About 45 per cent of the variable costs of wheat production went on fertilizers and 10 per cent on pesticides (Table 1), yet the yield response to fertilizers was only about twice as big as the response to pesticides.

EXTERNAL COSTS OF PEST CONTROL

Table 9 shews the estimated materials and external costs of the pesticides applied to the national wheat crop in the earlier years of this decade. The costs have been averaged over the whole acreage : for example, though it may have cost a farmer about £0.4 to apply a chemical to an acre of wheat only about half the national acreage needed herbicides, so the optimum cost spread over the full acreage was about £0.2 per acre nationally.

Table 9

Actual and Optimum Estimated Mean Costs of Pesticides Believed Applied to the National Wheat Crop, 1960 to 1964 and Estimates of Some of the Associated External Costs

Factor	£/Acre Averaged over the National Crop Estimated Actual Cost	Estimated Optimum Cost
Input of Pesticides at Market Prices:	0.73	0.43
External Costs:		
1. Application Costs	0.29	0.17
2. Phytotoxicity and Overspill	1.10	0.01
3. Assessing Need for Treatment	0.05	0.40
4. Sample Uncertainties	0.20	0.10
5. Research and Investigation	0.05	0.05
6. Miscellaneous Risks	? 0.15	? 0.05
Total Estimated External Costs:	1.84	0.78
Likely Total Costs:	2.57	1.21
Estimated Gross Returns (Table 7):	4.06	
Likely Net Returns:	1.49	2.85

The data in Table 9 illustrate firstly what probably happened during the years in question, and secondly what might have happened if treatments had only been applied when necessary: in practice, growers spent approximately £0.73 per acre on pesticides. With optimum treatment - that is, fully effective application of the right materials in the right places at the right times - expenditure on pesticides could have been cut to about £0.43 per acre nationally.

The Gross Return of £4.06 per acre is equivalent to 3.1 cwt and is 0.2 cwt more than implied in Table 8. This is a rounding-off error. The actual total cost/benefit ratio was of the order: (4.06/2.57) = 1.6, while the optimum was about: (4.06/1.21) = 3.4.

The External Costs in Table 9 were based on the following considerations:

1. Application Costs. It is sometimes argued that farmers pay a man's wages whether he is spraying or not, and that there are few cases where an extra man is employed solely to do arable crop spraying. It is also said that tractor and sprayer depreciation are too small to be costed in per spray-acre terms. At most, fuel costs should be charged to the Spray Account. However, in national terms it is reasonable to expect a re-allocation of resources if there was a substantial fall in demand for spray equipment. A basic figure of £0.38 per acre (Nix, 1961) has therefore been assumed in Table 9. The value of £0.29 in the "actual" column implies that only about 75 per cent of the wheat acreage was in fact sprayed; and the difference between the actual and optimum values reflects the cost of applying unnecessary treatments.

2. Phytotoxicity and Overspill. The largest external cost arose from inadequate, and probably unnecessary, treatment with herbicides on about 683,000 acres annually, giving an estimated total loss of about £2.19 millions, and unnecessary use of seed dressings at a loss of approximately £0.18 millions. It is sometimes said that cereal herbicides simplify harvesting, and their use gives cleaner grain samples. Merchants charged about £0.15 per cwt, equivalent to a per acre charge of £7.5, for cleaning grain in 1963 to 1964, and a big saving on re-cleaning costs would compensate for the 1.8 cwt yield loss, and waste of materials, from unprofitable herbicide use. Many likely sources of information on this matter have been approached, but it seems that there are no objective data.

3. Assessing the Need for Treatment. Optimally, seed would need special examination to identify specific pathogens and determine the real need for fungicidal treatment. The present Statutory Tests for purity and germination do not distinguish between good samples and samples badly infected with the currently important seed-borne diseases. It has also been assumed that each of the 44,000 farms with more than 10 acres of wheat would need visiting twice a year to sample potential wheat fields and assess the need for pest and weed control measures. In practice, few fields are expertly sampled, and the entry of £0.05 in the "actual" column is intended to cover the full costs of such visits, and of the regional sampling done to assess the likely incidence of pests like wheat bulb fly and leatherjackets.

4. Sample Uncertainties. On present knowledge it is unlikely that a practical series of field tests would give unequivocal answers about the need for treatment in every case. Experience with wireworms suggests that correct advice would be given four times out of five. Some unprofitable applications would be made, even under optimum conditions, and an equal number of cases would need an extra sampling visit to decide whether marginal cases should be treated. Sampling uncertainties are greater in practice than they would be under optimum conditions: there is, for instance, a tendency for a majority of growers to respond to area spray warnings though the crops on which the warnings have been based may not be fully representative of all the crops in the area. The "actual" estimate of £0.2 under this heading therefore includes overspill seed dressing treatments, at an estimated national cost of £0.09 per acre.

5. Research and Investigation. Over 200 kinds of pesticide investigations were noted in Appendices 2A to 2F of the 1964 Report of the A.R.C. Research Committee on Toxic Chemicals. Many of them needed costly equipment, facilities and staff. It is doubtful whether these investigations, and others which may have been omitted, cost much less than £1 million per annum. About 10 per cent of this might be costed against wheat on the grounds that about 10 per cent, by weight, of the active ingredients used annually in the early 1960's were used on wheat. Thus the annual per acre debit would be approximately £0.05, a figure which might be increased to cover the cost of advisory and extension work on wheat problems, only part of which was included under item 3.

6. Miscellaneous Risks. Arbitrary sums to cover accidents like drift damage, loss of revenue from shooting rights, and the chance that over-use of some materials will give rise to pesticide resistance problems which may need more costly controls. Because there was some overspill use in practice, the "actual" risk figure is put higher than the optimum figure.

DISCUSSION

These data are not perfect but are the best available. If the assumptions which underlie the various computational steps are valid, it seems that our wheat pest, disease and weed, control policies could have been better integrated. In particular, the external costs of phytotoxicity should have been eliminated, and the N.A.A.S. has recently made encouraging progress in this sphere, both in determin yield depression and in advising growers against unwise use.

If this source of loss is eliminated there is still room for improvement in the sense that the actual total per acre costs would still exceed the optimum by about £0.27 assuming the same pest situation as in the earlier years of this decade. This is equivalent to about £500,000 per annum. Perhaps we should try for the best of both worlds: increase actual investment in assessing the real need for treatment because success here would cut the overspill treatments which account for appreciable proportions of items, 1, 4 and 6 in Table 9. I look forward to Professor Smith's comments, particularly on whether we could improve our pest/pathogen/weed control input and output by using more non-chemical methods.

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SESSION 2

DISCUSSION

Dr. N. W. Hussey: From the wide field of integrated control topics touched upon by our six speakers, I would like to draw attention to those which also have a bearing on our own work at the Glasshouse Crops Research Institute.

I should say at the outset that the greatest stimulus to interest in integrated control arises with the development of resistance in a principal pest. Both Dr. Dicker and myself are only too well aware of the scale of the pest control problems which have followed the wide resistance spectrum evolved by tetranychid mites.

An important method of integrated control concerns cultural adaptation. Dr. Dicker has referred to the banding of apple trees for the trapping of codlin moth larvae, while Dr. Hull has mentioned the importance of early sowing and the isolation of seed crops in control of beet viruses. Our own work has developed a method of controlling red spider mite by preventing winter diapause through artificial lighting. Dr. Empson mentioned the important question of crop rotation. There is no doubt that other cultural systems may well have to be reconsidered where the present trend towards continuous cropping is extended.

Professor Smith has emphasised the establishment of economic damage thresholds and I cannot stress this requirement too much. Damage assessment studies must be made on all stages of crop growth. I would further predict that the capacity of a crop to compensate for some degree of damage will assume an increasing importance in our manipulation of pest populations in integrated systems. Both Professor Smith and ourselves have stressed the importance of manipulating pest populations and our work has emphasised the need for establishing a uniform distribution of both pests and their natural enemies if practical results are to be obtained. It is possible, therefore, that the programmed release of natural enemies may find a place even in outside cultivations along the lines we have developed under glass. It is indeed possible that Dr. Dicker may find such methods preferable to natural spread from natural enemy reservoirs.

Acceptance by the growers must remain a cardinal point for the commercial exploitation of integrated control. They will expect reliability as well as a degree of economic advantage from the use of these techniques. But above all, they will often have to accept the need for the purposeful introduction of pests to ensure their natural distribution. Such "inoculation" will probably be the hardest point to put across to the agricultural industry.

Most speakers have referred to the need for selective pesticides. I would like to draw attention to the fact that we must consider the effect of these pesticides on behaviour in addition to their lethal effects. At the present time scant attention is being paid to this vital factor, which limits all attempts to integrate chemical and biological processes.

In conclusion, I would agree with Dr. Dicker that a limiting factor in the development of integrated techniques may well be problems caused by the increase in numbers of some minor pests which have almost disappeared under the pesticide selection programme of the past two decades.

Professor Smith: I agree with Dr. Hussey - grower acceptance has to apply to any form of pest control, not just integrated control.

Mr. F. G. Ordish: Peru is famous these days for one thing - I refer, of course, to the 20 years of integrated control in cotton, which was introduced by legislation. Does such legislation exist in California? Is the grower compelled to use strip cutting of alfalfa, or does he just do it?

Professor Smith: The famous integrated control situation in Peru applies only to the Canete Valley and not to other cotton growing areas of Peru. Those integrated control programmes in California which have been most effective have been established without any enforcement through laws or legislation action. In other developing programmes only a portion of the growers co-operated. There are no plans for legislative persuasion to establish the programmes.

Sir Frederick Bawden: Why did Dr. Empson fear the impact of fungicides in grass and cereal crops when there had been no evidence of side effects from the use of fungicides on any other crop?

Dr. D. W. Empson: Fungicides have not been completely free from side effects. However, it was not a specific foreseeable hazard that prompted me to make my comment. I merely entered a plea for a thorough consideration of the broad implications of fungicide spraying on cereals.

Mr. T. J. Legowski: On the question of prophylactic and routine application of pesticides, I cannot help feeling that an increase in the price of some of them, e.g. wireworm seed dressings, might bring several advantages. It would tend to reduce their widespread application, it would compensate the manufacturers for some loss of business and it would presumably be desirable from the integrated control standpoint.

Dr. D. Price Jones: Price fixing is not an aspect of integrated control on which I feel competent to comment.

Mr. H. D. H. Womack: Would the panel please advise the conference who should recompense the farmer in the case of a major crop loss following the use of integrated control?

Similarly, who should recompense the farmer if a minimal rate of use of a pesticide was applied and crop failure ensued?

Professor Smith: Replying to Mr. Womack, the introduction and acceptance of new agricultural practices, such as integrated control, is not comparable with the sale and use of pesticide chemicals. The introduction of integrated control method is more comparable to the introduction of a new plant variety or a new cultural practice. Hence, when the procedure results in a failure, there is no recompense to the user, but rather there is a discontinuation of the practice.

A REVIEW OF RESEARCH IN BRITAIN ON THE EFFECTS OF PESTICIDES ON WILDLIFE

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INTRODUCTION

The terms "pesticide" and "wildlife" need defining. I shall use "pesticide" to cover all chemicals applied to control pests both plant and animal, and "wildlife" to denote all organisms which are neither pest nor domestic species. I shall speak mainly about the effects of insecticides on vertebrates and arthropods.

The pesticides in use today are not specific, and therefore they are bound to affect wildlife. This matters in so far as wildlife is valued by the community. Some species, such as insect pollenators, predators and parasites, and game birds are economically valuable, all are of actual or potential scientific interest, and the higher plants and animals are valuable for aesthetic and educational reasons. In the 19th century wildlife was ignored, or thought of only in terms of exploitation, but today it is considered increasingly as a living natural resource which has to be studied scientifically in order to be maintained and controlled, not only in nature reserves but throughout the country. In Britain the general policy to conserve wildlife was outlined in the White Paper Command 7122 and was given effect in the National Parks and Access to the Countryside Act and the charter of the Natural Environment Research Council.

Unintentional damage by pesticides has been extensive enough to stimulate research on their effects on wildlife in at least ten different countries. The aim of this research is to understand how pesticides affect wildlife so that advice can be given on how to reduce hazards. Research on wildlife complements programmes on pests, domestic animals and Man, and helps the community to get the best value out of both biological and chemical methods of control.

THE STUDY OF PESTICIDE EFFECTS

The medical and veterinary research worker are mainly concerned with hazards to individuals, and they rely on toxicological studies to assess hazard. On the other hand, those studying wildlife are primarily concerned with populations, and therefore must look at pesticide effects principally in ecological terms. The conservation biologist needs information about lethal doses no less than the medical worker, but he requires to know more about sub-lethal effects because these are much more likely to be important in the field, where a proportion of the population may receive a lethal dose. Further he is concerned with indirect effects as much as with direct ones because pesticides can cause population changes by affecting shelter, food, predators and competitors. All these types of effect may occur together and they may interact; and the systems treated are themselves highly complicated. Therefore in trying to unravel the relative importance of different factors the conservation biologist has an extremely difficult type of problem to assess. It is not surprising that we still know very little about the ecological effects of pesticides: this is as true in Britain as elsewhere.

RESEARCH IN BRITAIN

In Britain, research on the effects of pesticides on wildlife is mainly done by agricultural agencies as part of their work on pest control, and by organisations concerned with conservation. I shall not cover the first type of work as much of it has already been discussed in this morning's session on integrated control. In Britain conservation research on pesticides is the responsibility of the Nature

Conservancy which is a constituent body of the Natural Environment Research Council. Its Toxic Chemicals and Wildlife Division, which is based on Monks Wood Experimental Station near Huntingdon, was set up in 1960 following widespread reports of wildlife casualties in the field. Research on the effects of pesticides on wildlife is also done by the Infestation Control Laboratory of the Ministry of Agriculture Fisheries and Food in support of the Ministry's Regional Pest Officers. Observational and survey work has also been done by voluntary organisations, notably the British Trust for Ornithology, the Royal Society for the Protection of Birds and the Game Research Association. In addition a number of joint field and laboratory studies are in progress by chemical firms in conjunction with the Nature Conservancy, the Water Pollution Laboratory (Ministry of Technology), the Laboratory of the Government Chemist (Ministry of Technology) and the Forestry Commission. Increasingly chemical firms are asked to carry out field trials and observations in order to assess possible hazards to wildlife when new pesticides are first notified under the Pesticide Safety Precaution Scheme.

In Britain the main emphasis has been on the measurement of changes in wildlife populations throughout the country, whatever their causes, and on the effects of the persistent organochlorine insecticides. The latter have been studied especially because they were known to have killed many birds and mammals, and because, theoretically, they could - as a result of their persistence - affect areas outside the sites of application and even total populations of organisms. Research undertaken in recent years falls into distinct categories.

1) Measurement of population changes in indicator species.

2) Studies of organochlorine insecticide residues in wildlife.

3) Toxicological studies on the significance of organochlorine insecticide residues found in the field.

4) Field experiments on the effects of pesticides on populations.

Measurements of Population Changes

Vertebrate wildlife populations are particularly worth studying as they can be sensitive indicators of various forms of environmental malaise, particularly of that caused by widely dispersed pollutants. Unfortunately the practical difficulties of measuring populations of wild animals are so great that very few species have been studied. The advent of pesticides has acted as a valuable stimulus to this form of biological research. In Britain the following programmes are being done to assess population changes on the national scale.

1) Studies of certain widely distributed predatory birds. These are mostly organised by the Nature Conservancy and carried out with the help of voluntary bodies like the British Trust for Ornithology. Mr. Prestt will be describing this work later today (for references see his paper).

2) Annual censuses of birds on about two hundred farms in which each census area covers about two hundred acres. This work is organised and carried out by the British Trust for Ornithology with the Nature Conservancy's support (Williamson and Homes 1964).

3) Quantitative studies on the distribution of higher plants, vertebrates and certain invertebrate groups on a 10 kilometre square basis. This work is organised by the Biological Records Centre at Monks Wood. It measures changes in distribution, not in numbers.

4) Quantitative studies on changes of important wildlife habitats. Initially the work is being concentrated on hedges and is organised by the Toxic Chemicals and Wildlife Division at Monks Wood.

In addition many data on breeding success of British birds are obtained by the British Trust for Ornithology each year through its Nest Record Scheme and indirectly through its Ringing Scheme.

Several intensive studies of local populations have been or are being conducted. In one, chemical analyses are being made of samples of a predator and its food. In this case - the fish feeding Shag in the Farne Islands - there is no evidence to suggest that pesticides are affecting the population; the residue levels obtained do not indicate a hazard (Robinson et al. 1967).

In general, the information to date shows that certain raptorial birds have undergone unprecedented declines in the late 1950's and early 1960's, and have shown signs of recovery since 1966. The populations of other avian species have remained fairly steady or have fluctuated within normal limits in recent years. Firm conclusions about animals of other taxonomic groups cannot be made on the information available so far.

Studies of Pesticide Residues in Wildlife

This work was started in 1962 in order to discover the broad patterns of the distribution of persistent organochlorine insecticides in wildlife in the field. It showed that most specimens contained detectable residues of organochlorine insecticides, principally of pp'-DDE, pp'-DDT, pp'-TDE, dieldrin, heptachlor epoxide and BHC. Residues were obtained from a wide range of taxonomic groups, from all the main environments, including freshwater and the sea, and from all parts of the British Isles from the Shetland Islands to the south of Ireland (Moore 1965 a and b).

On average predatory animals feeding on vertebrate prey, particularly predatory birds, contained much higher residues than herbivores and insectivores (Moore and Walker 1964).

Perhaps the most striking finding was that all the eggs of seabirds examined (c. 200) contained residues of at least two insecticides; the total residue usually fell within the rather narrow range 0.4 - 3.5 ppm. This fact suggested that the eggs of seabirds might be particularly useful for monitoring changes of pesticide contamination in the environment (Moore and Tatton 1965). Since 1963 a small monitoring scheme has been operated by the Toxic Chemicals and Wildlife Division using seabird eggs from colonies in England, Scotland and Ireland. The results show that there has been no major change in contamination of British waters by the organochlorine insecticides during the last five years, although there are indications of a small decline in both DDT and dieldrin during this period (Moore in prep.).

Toxicological Studies

Much work has been done in recent years to discover the biological significance of residues of persistent organochlorine insecticides in wildlife. It has been done principally by the Infestation Control Laboratory at Tolworth, Shell Research Ltd at Sittingbourne, and by the Nature Conservancy at Monks Wood.

The agricultural departments investigate incidents in which there is a prima facie case that pesticides have caused the death of wild vertebrates. Birds and mammals are examined at Tolworth, and fish are examined at the Freshwater Fisheries Laboratory at Faskally, near Pitlochry. In addition, post-mortems are made on many specimens sent to Monks Wood. Chemical analysis of dead animals picked up after an incident often, but not invariably, give circumstantial evidence of the amounts of residues in various organisms which indicate acute hazard. For example, thirteen out of twenty-two raptorial birds picked up dead in Eastern England between January and April 1967 contained more than 10 ppm of dieldrin in the liver. More reliable results have been obtained experimentally in the laboratory under control conditions; feral pigeons have been used at Tolworth (Turtle et al. 1963), and Bengalese Finches at Monks Wood (Jefferies 1966). In general the results confirm the evidence obtained in the field, and have also emphasised the well known fact that there is much variation in response by different species to the same chemical. Work in progress at Tolworth is showing the relative toxicological importance of the metabolites of DDT (Turtle pers. comm.).

In estimating food chain effects one needs to know whether ordinary agricultural practices are likely to result in predators obtaining harmful residues from their prey. Analyses of marine organisms show that predators contain very much larger residues than their prey (Moore and Tatton 1965, Robinson <u>et al</u>. 1967). Similarly Prestt has found much higher residues in Herons than in the fish on which they feed (Prestt unpub.). In the terrestrial environment there appears to be a much greater variation in the size of residues in potential prey organisms. Laboratory studies by Jefferies and Davis (in press) show that earthworms may accumulate considerable residues. They show that when Song Thrushes feed upon them, the rate of intake is important: a Song Thrush fed large amounts quickly died and contained a much lower residue at death than another fed a larger total amount spread over a longer period. Laboratory work by Jefferies (in prep.) shows that only seven voles, carrying dieldrin residues at levels likely to be obtained under normal agricultural practices, are enough to kill a Kestrel. Much of this work is being done in order to determine whether birds are mainly affected by ingesting a few highly contaminated organisms or by a more gradual uptake of smaller residues. From the evidence obtained so far it appears that acute effects are more likely to occur as a result of consuming a few prey with large residues. However the prolonged uptake of smaller amounts of pesticide might result in deleterious sub-lethal effects: this is being investigated.

In the course of population studies evidence of abnormal reproduction and behaviour has been obtained in the field in recent years. Striking declines in reproductive success have occurred at the same time as an increased incidence in egg breaking and in delayed breeding among certain birds. A study of egg shell thickness by Ratcliffe at Monks Wood showed that egg shells of several species of raptorial birds were highly significantly thinner after 1946 than before (Ratcliffe 1967). In a situation in which some of the population is suffering from lethal doses it is likely that others are effected by sub-lethal ones; accordingly several studies have been made by the organisations mentioned previously to determine sub-lethal effects and their relation to pesticide intake. Work by Jefferies (1966) on the Bengalese Finch shows that relatively large sub-lethal doses of DDT affect the viability of the young of treated birds. Jefferies (1967) has also demonstrated that sub-lethal doses of DDT can lengthen the period between pairing and ovulation. If dieldrin has a similar effect this may account for the otherwise inexplicable delayed breeding of the Wood Pigeon noted by Lofts and Murton (1966). Work by Jefferies and others (in prep.) shows that both dieldrin and DDT can cause a decline in egg shell thickness in the Japanese Quail under laboratory conditions. These insecticides also cause an increased number of broken eggs. So laboratory findings support the hypothesis that the changes in egg shell thickness, which have occurred in species with large average residues of organochlorine insecticides, are due to these substances.

Work by Moriarty (in prep.) on the effects of DDT and dieldrin on the butterfly <u>Arglais urticae</u> and the grasshopper <u>Chorthippus brunneus</u> has demonstrated that sub-lethal doses can cause a lowering in fecundity, latent toxicity and abnormal emergence in insects. Dempster (in press) has shown that if DDT is present in the soil at the concentration of 10 - 12 ppm it causes a significant decrease in feeding by the beetle <u>Harpalus rufipes</u>. However most of the effects of sub-lethal doses in insects occur when these approach the lethal dose.

In general, laboratory work on sub-lethal effects shows that the abnormalities observed in the field could be due to organochlorine insecticides. It is much more difficult to assess the significance of sub-lethal effects on population numbers.

Field Experiments on the Effects of Pesticides

For obvious reasons most work of this kind has to be done on invertebrates; Dr. Dempster will be describing his studies on the effects of DDT applied to a brassica crop. His work shows the extremely complicated nature of the effects of one pesticide when it is applied to a complicated system like a crop. Later Mr. Newman will be describing the indirect effects of dipyridyl herbicides on aquatic systems.

In assessing the effects of a pesticide on vertebrate species one generally has to rely on circumstantial evidence supported by relevant laboratory studies of the kind mentioned above. However one field experiment on a population of wild birds has been started.

BACKGROUND STUDIES

Pesticides do not act in a vacuum; a full assessment of their effects must always take the other major factors into account. In Britain today destruction of habitat is almost certainly one of the most important factors, particularly the wide-spread destruction of hedges, which provide a suitable habitat for most of the wild species found on farmland. Accordingly special studies on this subject are being made by the Toxic Chemicals and Wildlife Division at Monks Wood and are being integrated with studies on pesticides. Recent work (Moore et al. 1967) shows that hedge destruction varies from district to district; in one area in Huntingdonshire 70 per cent of the hedge mileage has been destroyed since the war.

CONCLUSIONS

In recent months a rigorous assessment has been made on the probable effects of organochlorine insecticides on wildlife for the Further Review of the Persistent Organochlorine Pesticides used in Agriculture and Food Storage which is being made by the Advisory Committee on Poisonous Substances used in Agriculture and Food Storage. When the laboratory studies are related to the field observations the following conclusions are reached :-

1) Aldrin, dieldrin and heptachlor cereal seed dressings, particularly when used between January and April, can be extremely hazardous to birds and mammals which feed on the grain which is left on the surface of the soil, and indirectly to their predators.

2) The recent unprecedented declines of certain raptorial species are almost certainly attributable to the use of persistent organochlorine insecticides.

3) The reported declines of some other species are likely to be mainly due to habitat changes. However an increase in the present levels of environmental contamination by persistent insecticides might well affect other species.

4) The residue surveys show that organochlorine insecticides are widely distributed in the environment, and that these highly persistent compounds are intrinsically uncontrollable. Therefore, actually and potentially, they provide the greatest hazard to wildlife in Britain today.

5) The various voluntary bans on aldrin, dieldrin and heptachlor have already caused a recovery in all the seriously affected species. The new compounds replacing the organochlorine insecticides appear to be far less destructive to wildlife, and are much less likely to lead to widespread environmental contamination. Therefore, they are welcomed by conservation biologists.

Research work in Britain has emphasised the need to carry out quantitative studies in the field as well as in the laboratory, and to integrate the two types of research. It has also shown the need for effective cooperation between Industry, Government research laboratories and voluntary bodies. One of the byproducts of this cooperation in Britain is that most conservationists understand the value of pesticides, and most industrialists understand the value of wildlife. By working together we have already gone a long way in reducing avoidable hazards to wildlife. Yet the work already done has shown how little is known about the populations affected directly or indirectly by pesticides, and therefore we cannot afford to be complacent. Already, pesticides have stimulated much fundamental ecological work, which in the long run cannot fail to help Crop Protection, the branch of applied ecology which brings us together here at Brighton.

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SESSIONS 3 AND 4A

DISCUSSION

Dr. H. H. Glasscock: Are there any marked differences between the levels of organochlorine compounds found in wildlife in the different countries of Europe and in the U.S.A. as compared with those countries with less sophisticated methods of agriculture?

Dr. N. W. Moore: Recent work shows that the levels of organochlorine insecticide residues in sea bird eggs are considerably higher in California than in Britain. Comparable information on terrestrial species is not available, but in general, contamination in the United States appears to be higher than in Britain. Information on contamination in Europe and elsewhere is insufficient to make a valid comparison with Britain and the United States.

Mr. I. Prestt: Residues in Peregrine eggs in the U.S.A. are similar to those found in Peregrine eggs in Britain.

Mr. D. S. Papworth: The papers presented this afternoon are an interesting contribution for those called upon to attempt the evaluation of risks to wildlife that may follow the introduction of a new chemical, or, the new use of an existing chemical. In operating the Pesticides Safety Precautions Scheme during the last few years, increasing emphasis has been placed on the need to supply data showing that the commercial use of a chemical in the field will not harm wildlife. To date the principal information has consisted of the toxicity of a chemical to at least one avian species, fish, and honey bees. Two years ago at this same Conference we heard an interesting paper on the technique of screening soil samples for invertebrate species to show the effects of adding an active ingredient to such soil. As one called on to advise our industrial colleagues as to how risks to wildlife may be assessed, can this afternoon's speakers say whether their present research work, or work to be done in the immediate future, is likely to widen the number of indicator species that could reliably be used for this task? Clearly such field work that may arise in the increase of suitable indicator species will need to be economical of labour resources as well as improve the reliability of such evaluations.

Dr. N. W. Moore: My personal view is that extra resources for studying possible effects of pesticides on wildlife will necessarily be limited, and should not be used on toxicological work on an extra indicator species, but should be used for carrying out extensive objective surveys in the field during the first years of use of a new pesticide. This would be a much better way of detecting unforeseen hazards after routine toxicological testing.

Sir. Frederick Bawden: Do any of the raptorial species which have declined, feed on rabbits?

Dr. N. W. Moore: No. The only British raptorial species which feeds extensively on rabbits is the Buzzard, and this has not shown any extensive recent population declines.

Sir. Frederick Bawden: Has the food of birds of prey which have declined, changed in recent years?

Dr. N. W. Moore: These birds are very catholic in their taste. It is possible that the populations of some prey species may have changed slightly but there is no evidence to suggest that the total bird biomass, and hence the available food supply, has changed significantly.

Sir. Frederick Bawden: Dr. Mellanby, which do you consider to have had the greatest effect on wild birds in recent years: loss of habitat or chemicals?

Dr. K. Mellanby: There has been no significant decline in available habitat or of nesting sites for the affected species. In some other species decline in suitable habitat probably has had a local effect.

Mr. I. Prestt: New Forestry Commission plantations have increased the available habitat for the Sparrow-Hawk. As these woodlands often replace open moorland, they have also resulted in the local increase in numbers of many other birds.

Mr. G. F. H. Whitney: In view of the resurgence of at least some species of raptorial birds since 1966 are we to conclude that chlorinated pesticides other than the three compounds (aldrin, dieldrin and heptachlor) which have been discontinued, were not responsible for the former decline of these species?

Mr. I. Prestt: The recoveries of the Peregrine, Sparrow-Hawk, Kestrel and Barn Owl are not yet widespread. While we are reasonably confident that the decline was mainly caused by aldrin, dieldrim and heptachlor seed dressimgs, we cannot rule out the possibility that sub-lethal effects of these and/or DDT have affected breeding success.

Dr. M. R. Smith: Could the decrease in numbers of the raptorial birds be due to cold weather effects 1946 to 1947?

Mr. I. Prestt: The decline in numbers did not take place until the late 1950's. There was a decline in breeding success in the late 1940's, but this did not cause a decline in breeding populations. It is well known that recovery from hard winters is rapid - rapid recovery was not observed in the birds under consideration.

Dr. J. Robinson: Mr. Prestt has subdivided the samples of predator birds into four groups (those in which the cause of death are shooting, injury, disease or unknown). Has he compared the residues in the four groups?

Mr. I. Prestt: No, not yet because the numbers involved are still too small for statistical analysis.

Dr. J. Robinson: Dr. Moore and Mr. Prestt have both mentioned tissue levels as an index of death by poisoning and I suggest that the concept of "lethal tissue concentration" required fuller definition than they have given. Further, Mr. Prestt mentions that the residues in the liver of experimentally poisoned birds "are considerably in excess of those found in dead wild birds thought to have died from dieldrin poisoning", and he implies that the results from the experimental birds are not applicable to wild birds. However, he appears to be inconsistent in that he uses a level of 10 ppm dieldrin in the liver as the index of mortality and this level of 10 ppm is, so far as I am aware, based upon experimental studies with feral pigeons. The toxic liver levels of 10 ppm dieldrin and 30 ppm DDT are quoted by Dr. Moore and Mr. Prestt. Would Dr. Moore indicate the evidence upon which these estimates are based?

Dr. N. W. Moore: The level of 10 ppm of dieldrin in the liver, which has been used as a rough index of probable toxic hazard, was based partly on the work of Turtle and others on feral pigeons and partly on other evidence. It is not used as anything other than a useful approximation. Recent work on Song Thrushes and Kestrels at Monks Wood has confirmed the general correctness of the dieldrin figure.

I should emphasise that if the correct figure was found to be considerably higher or lower than 10 ppm it would not affect the central argument about the probability of aldrin and dieldrin having caused the decline of raptorial species.

With reference to residue levels found in predators, it should be noted that it is extremely difficult to obtain specimens of birds of prey from areas where pesticides are widely used; most of those analysed came from areas where pesticides are believed to be having relatively little effect on the populations.

Mr. I. Prestt: Work at Monks Wood shows that the greatest caution must be taken in extrapolating laboratory data to field situations - the results of some laboratory studies can be misleading e.g. much higher residues are found in the tissues of inactive raptorial birds killed by dieldrin in laboratory experiments than those found in birds which have been exercised daily.

Dr. J. Robinson: There appears to be typographical confusion in Mr. Prestt's paper regarding DDT and DDE (p. 29, line 13 from bottom, 30 ppm pp'-DDT; line 2 from bottom 30 ppm pp'-DDE, and the histograms, pp'-DDE, not pp'-DDT).

Mr. I. Prestt: These are not typographical errors. Results of DDT type residues in my paper refer to DDE. Recent work at Tolworth has shown that DDE is more toxic to birds than DDT, and therefore the use of 30 ppm as a very approximate index can be reasonably taken to hold for DDE as well as DDT.

Dr. J. Robinson: The Table on p. 32 implicitly assumes that the effects of dieldrin + pp'-DDE + heptachlor epoxide are additive and independent. Does Mr. Prestt have any evidence to support this?

Mr. Prestt: The Table on p. 32 does not assume additive effects; the fifth column of figures is of birds possessing both > 10 ppm dieldrin and > 30 ppm DDE. However, there is evidence from two recent American papers that effects of organochlorine insecticides can be additive.

Dr. J. Robinson: With regard to the references by Dr. Moore and Mr. Prestt to endocrinal effects, egg shell breaking, etc. it is important to take into account the concept of a dose-response relationship; have the various dose-response relationships been evaluated (in terms of either tissue concentrations or egg levels) and how do these compare with the concentrations found in wild birds and their eggs?

Mr. I. Prestt: Dose response of the Bengalese Finch to DDT is being studied in terms both of tissue concentration and egg levels. While levels of DDT in the field are generally small, the laboratory work suggests that a small uptake of DDT can delay ovulation.

Dr. J. Robinson: How precise is the correlation between the onset of declines in the populations of Sparrow-Hawks and Peregrine Falcons and the introduction of aldrin, dieldrin and heptachlor into British agriculture? Some authors speak of the onset of the decline occurring in the mid-fifties, others of the late fifties.

It may be appropriate on this point to draw attention to the Nest Record Scheme and the Bird Ringing Scheme (particularly the number of pulliringed each year). Are the results of these schemes suitable for use as indicators of changes in the population status of these birds? If so, are the results considered to be compatible with the claim that the changes are correlated with the usage of aldrin, dieldrin and heptachlor.

Mr. Prestt: The results are compatible. There is no evidence that the common birds have shown significant declines. On the other hand the correlation of the declines of the raptorial species with the use of aldrin, dieldrin and heptachlor in recent years is very close.

Dr. J. Robinson: Mr. Prestt has contrasted the mode of intake of Peregrines and Sparrow-Hawks with that of Herons. Have systematic surveys been made of the residues in the prey of the terrestrial raptors comparable with those of the food of Herons.

Mr. I. Prestt: We know that residues in the prey of terrestrial predators at the time of spring sowing can contain much larger residues than have ever been recorded in the food of the Heron.

Dr. J. Robinson: Mr. Prestt said that British birds of prey cannot be bred in captivity. Nevertheless biologists at the Patuxent Laboratory in the U.S.A. have succeeded in breeding Kestrels in captivity.

Dr. N. W. Moore: The species bred at Patuxent is the American Kestrel (*Falco sparverius*) which is quite different from our species.

Dr. J. Robinson: With regard to Dr. Moore's comment that in birds fed dieldrin and DDT an increase in the breakage rate of eggs has been observed, it is perhaps pertinent to point out that in experiments in Tunstall Laboratory in which quail and chickens have been fed diets containing dieldrin no such effect has been observed. The quail eggs contained about 10 ppm (from birds fed 10 ppm dieldrin) and about 30 ppm (from birds fed 20 ppm dieldrin). The chickens' eggs containing 10 ppm dieldrin showed no effect upon hatching success and survival of chicks; the quail eggs (containing about 20 ppm dieldrin) and the chicken eggs (containing about 30 ppm dieldrin) showed some effect upon chick survival only.

Dr. J. Newman: If you see smoke pouring out of a hotel door you do not ask for mathematical proof that the building is on fire before doing something about; practical decisions by those controlling pesticides have to be used on the evidence available.

Mr. T. H. Coaker: Why has *Pieris* apparently become less common in Britain in recent years if survival is better when crops are sprayed with DDT?

Dr. J. P. Dempster: The factors determing the overall abundence of *Pieris* are not known. *Pieris* is only a pest in certain years coinciding with immigration from the Continent.

Mr. T. H. Coaker: Have you any evidence that the effects of organophosphorus insecticides on soil animals have any effect on soil fertility?

Mr. J. R. Lofty: No.

Dr. J. Newman: Chemical effects are likely to be insignificant compared to those caused by cultural operations.

Mr. W. Wilkingson: Do you break down the animal groups quoted? We do similar work at Jealotts Hill and select key species to check on the balance within such groups, because we feel that they are not always homogeneous in habit or habitat.

Mr. J. R. Lofty: Only to a limited extent.

Mr. M. J. Way: We have done some experiments on the effects of in-row treatments of phorate (1 lb per acre) and menazon (2 lb per acre) in drills two feet apart. The local high concentrations initially affected earthworms in and between the rows as indicated by decreased feeding on leaf discs put in the soil.

This effect did not last more than about three weeks. Some Collembola and mites were killed in soil 3 inches either side of the treated band and also 3 to 4 inches below it, but they were unaffected above it. Menazon had no observed effect on the soil fauna except in the treated land. We concluded that even with phorate the effects were so trivial that they could be discounted.

I should like to ask Mr. Lofty why in his experiments the same treatment increased the numbers of certain soil organisms.

Mr. J. R. Lofty: The differences could be related to differences in the crops.

PESTS AND DISEASES OF VEGETABLES GROWN UNDER GLASS AND THEIR CONTROL

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INTRODUCTION

In the past 20 years great changes have taken place in the production of vegetables under glass. In former days there were three principal types of culture:

(a) One tomato crop per year in heated glasshouses.

(b) One crop of lettuce followed by one tomato crop per year in unheated glasshouses.

(c) One crop of lettuce and one crop of cucumber per year in Dutch lights.

Although very few effective pesticides were available, these crops could be grown successfully thanks to the relative short growing period. To-day the glasshouse industry has quite changed. The Dutch lights have disappeared completely, tomatoes and cucumbers are grown for 8-10 months, early tomatoes are followed by late cucumbers or vice versa, three crops of lettuce are grown consecutively etc. These changes have had considerable influence on the pests and disease situation. On the one hand the host-plant is available to the pathogen or insect over a longer period, whilst on the other the period of "natural disappearance" of the pests and diseases has become much shorter. This means higher populations and greater chances of survival for both airborne and soilborn pests and diseases.

A few examples will demonstrate the consequences of the changes in growing techniques. Formerly powdery mildew in cucumbers was practically unknown and no control measures were necessary. The cucumbers were grown under Dutch lights from March to September and, even if the fungus became established at the end of the season, it has disappeared completely by the time the new crop was planted. To-day, cucumbers are grown throughout the year so that the fungus cannot only survive easily, but can constantly spread. In this way mildew has become one of the main troubles in cucumber growing.

In lettuce production only one crop used to be grown per year. Thanks to new varieties and new growing techniques 2, 3 or even more successive crops can be grown. Rhizoctonia has become an important disease especially in autumn and winter.

In general the virus problem has become worse over the last 20 years. Not only have the known virus diseases caused greater losses, but new diseases have appeared. An example of a new virus problem caused by changes in cultural methods is the occurrence of cucumber mosaic virus (Cucumis virus 1) in lettuce. In some cases lettuces are propagated in the same house as that in which a late crop of cucumbers has been grown. The crop is therefore frequently infected with the virus. As the disease is aphid-transmitted, it will easily infect young lettuce plants and so cause a complete failure of the crop.

It should be emphasised that most of the cultural changes have only become possible through the availability of modern insecticides and fungicides. This also holds for the soilborn diseases which are posing a greater threat as cropping becomes more intensive. To prevent crop losses soil disinfection is, therefore, absolutely necessary. To-day good chemicals are available for this purpose.

SOIL BORN DISEASES

Apart from grafting on resistent rootstocks (which is not dealt with in this paper) nearly all growers annually adopt soil disinfection in some way or another. In cucumber growing this is practically always done by means of steam. The main soilborn diseases that attack the roots of cucumbers are: Fusarium sp., Sclerotinia sclerotiorum, Phomopsis sclerotiodes and rootknot nematoes (Meloidogyne sp.). The fungi mentioned are difficult to kill by chemicals and so, to avoid any risk, steam-sterilization is the safest solution. Moreover, cucumber green mottle mosaic virus (Cucumis virus 2) can persist for many months in the soil and so cause considerable losses by infecting the next crop early in the season. To kill virus in the soil only steam is effective. Formerly soil steaming was done by means of Hoddesdon pipes. In this method much expensive labour is involved so that most growers have turned to steaming under plastic sheets. Although this method is certainly not better than the old system it is sufficiently effective under practical conditions. As steam-sterilization is done every year on specialized cucumber growing holdings high infestations cannot build up so that crop losses due to soilborn fungi seldom occur. An exception has to be made for rootknot nematodes. Although they are readily killed by high temperatures, a few may escape the treatment. These individuals may find ideal conditions for development so that unexpected heavy attacks may occur even after steaming of the soil. Additional measures are therefore generally taken to prevent this attack. If the grower has sufficient time before the next crop is planted, nematocides like D.D. or E.D.B. are used. Most growers, however, prefer to use granules containing dibromochloropropane, which are applied prior to the planting of the cucumbers.

The situation with tomatoes is much more complicated. The main soilborn diseases affecting tomato growing are corky root and rootknot nematodes, whilst Verticillium wilt and potato eelworm occur only incidentally. Steam sterilization is restricted to the culture of tomatoes in heated glasshouses. For this purpose the grower usually has his own equipment. On holdings without heating, the steam sterilization has to be done by outside contractors with a consequent heavy expense. Besides steaming, the grower may choose between different soil disinfectants. They are D.D., E.D.B., chloropicrin, metham-sodium while recently methylbromide has become available. All these chemicals act as fumigants after they have been injected into the soil as a liquid and allowed to evaporate there. If this is done in the proper way the vapours penetrate the soil thoroughly and achieve a good control.

The choice of the chemical to be used depends on the kind and severity of the attack. Where only nematodes have to be controlled D.D. (50 to 60 cc per m^2) or E.D.B. (45 to 55 cc of a 10 per cent formulation per m^2) is applied. For the control of soilborn fungi chlropicrin (35 to 40 cc per m^2) has up to now been widely used. As the nematocidal action of chloropicrin is rather poor under practical conditions about 10 per cent pure E.D.B. is added, when both fungi and nematodes have to be controlled. The use of metham-sodium is restricted to those cases where the level of soil infestation is low, as the dosage used (70 to 100 cc of the commercial product per m^2) has only limited effect. All the soil disinfectants mentioned have the disadvantage that the period between application and planting of the next crop is relatively long, especially if the soil temperature is low. Chloropicrin has the further disadvantage that it may easily cause damage to crops in the neighbourhood. This hazard can greatly be reduced by covering the soil with plastic sheets after the application, but under unfavourable conditions damage may still occur. For these reasons there is an increasing interest in the use of methylbromide. As the boiling point of this fumigant is about 4°C, it evaporates very quickly and the interval between application and replanting can be short even at low soil temperatures. Special measures have to be taken to achieve the optimum effect and to avoid any hazard to the applicators. The measures include: the use of a specially designed motor injector, injecting the chemical at least 20 cm deep, covering of the soil with plastic sheets immediately after the application, the wearing of special gasmask etc. If methylbromide is used in the right way and at the right dosage (75 g per m^2) it is the most effective soil steriliser known.

An important side-effect of soil sterilization is the phenomenon called growth stimulation. In terms of production this means that apart from killing pathogens, there is a definite increase in growth after the application on these chemicals. The degree of growth stimulation depends on the material used. It is greatest with methylbromide, less with chloropicrin and metham-sodium and neglible with D.D. and E.D.B.

Thanks to the herbicidal effect of soil disinfection, any further weed control is generally unnecessary in vegetable growing under glass. From this point of view steaming and methylbromide are therefore the most effective.

It should be mentioned here that chemical soil disinfection is only done by contractors, who are well equiped and well trained.

From the foregoing it will be clear that soil disinfection is one of the most important tools in glasshouse production, which has become a generally adopted routine to avoid any risk of crop losses due to soilborn diseases.

AIRBORNE PESTS AND DISEASES

In this section the airborne pests and diseases will be dealt with separately for these different crops.

Cucumbers

As already stated great changes have taken place in the growing of cucumbers. Production continues all the year round with plants growing for eight months or longer in the same house. The method of culture has also altered greatly. Formerly, the plants were trained and pruned regularly. For the application of pesticides this was of great importance since all parts of the plants could easily be reached by the chemical sprays. Under the modern cordon-system practically no training is done, pruning is restricted to a minimum and the old and dead leaves are left on the plant. Under these conditions it is very difficult, if not impossible, to cover all the leaves with pesticides. It looks therefore, as if the chemicals used in cucumber growing are less effective than formerly. To achieve efficient control more emphasis must be laid upon the application of insecticides and fungicides early in the growing season.

For the control of cucumber mildew (Sphaerotheca fuliginea) dinocap and oxythioquinox are widely used. Although they have an eradicant action, they are generally used as a preventative. Early in the growing season application is by dusts but later on, as the fungus has established itself, as sprays.

For the control of red spider three types of acaricides are currently available: tetradifon, dicofol and organophosphorous compounds. Although tetradifon has been applied on a fairly large scale, its use has recently decreased considerably due to unpredictable damage to the cucumber leaves. For the last 4 to 5 years, dicofol has been the main acaricide used, giving very good results. This year, however, dicofol has failed to give sufficient control of red spider on several holdings and it is to be expected that resistance will cut back the use of this material. The organophosphorous compounds used include: parathion, diazinon, malathion, mevinphos and dichlorophos. Their effect on red spider is relatively poor due both to lack of residual effect and resistance of the mite. They are however, used very frequently to control white fly (Trialeurodes vaporariorum) and aphids (mainly Aphis gossypii). The latter is responsible for the transmission of cucumber mosaic virus (Cucumis virus 1) especially in late crops of cucumbers. Some organophosphorous compounds have however a peculiar effect on cucumber plants if they are used very frequently (e.g. once every 3 to 5 days which may be necessary for an effective control of some pests). For some years there have been complaints from growers about the dying off of young fruits after application of certain representatives of this group. This practical observation was confirmed in experiments carried out at our Station. (Table 1.)

Table 1

Effect of frequent application of acaricides and insecididos on the production of cucumber

Experiment 1		Experiment 2	
Chemical	Number of fruits	Chemical	Number of fruits
Parathion	118	Diazinon	140
Dichlorophos	39	Malathion	136
Mevinphos	50	Mevinphos	89
Dicofol	152	Control	152
Control	148		
Applied twice a week		Applied once a week	

It is evident that mevinphos and dichlorophos may greatly reduce the fruit production whilst parathion may also have an adverse effect. Other chemicals have practically no such effects. Although this phenomenon does not always occur, it is inadvisable to use the first two mentioned insecticides more than once in a fortnight.

At the present time red spider is causing serious difficulties but it is to be expected that this will be short-lived, as many new acaricides have been developed some of which will gradually become available to the growers.

Tomato

Formerly, leaf mould (*Cladosporium fulvum*) was the main disease in tomato growing under glass for the control of which zineb, maneb or Bulbosan (trichlorotrinitrobenzene) were used. Early in the growing season these materials were applied as dusts but later on as sprays. Spraying with zineb could not be repeated too often if visible residue of the fruits was to be avoided. Frequent applications of maneb wettable powder tended to cause hardening of the plant. The advantage of Bulbosan has been that it did not harden the plant and gave practically no visible residue. Since the introduction of varieties resistent to leaf mould, the application of fungicides for its control is no longer necessary. Omissing the fungicides, however, frequently resulted in outbreak of *Phytophthora* mainly on the fruits and the stem of the tomato. To prevent this, zineb or maneb must be applied regularly.

Botrytis cinerea is currently the main problem in the growing of tomatoes especially in non-heated glasshouses. Although the damage can be restricted by cultural measures, it is often necessary to apply chemicals to prevent crop losses. The most effective fungicide for this purpose is a formulation of thiram in oil. To get a reasonable degree of control the application has to be repeated to regular intervals. By doing so the plant is hardened badly, which in itself may have an adverse effect on the fruit production.

In Table 2 the effect of thiram in oil on the production can be judged from a comparison of control of a heavy attack of *Botrytis* with that of application in a disease-free crop.

Table 2

Influence of thiram in oil on the production of tomatoes

	Heavy infestation with *Botrytis*	*Botrytis* free crop
Without thiram	235 kg	348 kg
With thiram	299 kg	325 kg

Although this formulation of thiram gives a good control of *Botrytis*, it is impossible to say whether its use will be economic or not. In the case of a severe attack it will be economic but in case of a slight attack probably not. The severity of the disease cannot be predicted as this depends largely on weather conditions. An alternative possibility for the control of *Botrytis* is the use of tecnazene smokes. This may inhibit the growth of the fungus for a certain period, but if the attack gets worse, the degree of control is insufficient.

Several fungi may cause "footrot" symptoms on tomato plants. These are: *Didymella lycopersici*, *Botrytis cinerea*, *Rhizoctonia solani* and *Phytophthora spp*. Generally *Botrytis* and *Rhizoctonia* only occur in the early stage of the growing period. The former is mainly caused by inefficient cultures. The latter is soilborn and may be controlled by soil disinfection or by spraying with quintozene. For the control of *Didymella* the planting hole may be treated with maneb before planting. If this is done in the proper way and infestation of the soil is not excessive, the technique is efficient. If, later on in the season, the stems are attacked by the fungus, it is practically impossible to control. *Phytophthora* footrot is another disease only discovered recently. Research is in progress to find the source of infection and to define suitable measures necessary to prevent the attack.

Until recently the only pests occurring in tomato growing were aphids and white fly. To control white fly, parathion is widely used with good results since it is able to kill all the developmental stages of this insect. It can, however, only be used up to three weeks before the picking begins. During the harvest period mevinphos and dichlorophos can be used. The latter insecticides have the drawback that they kill only the adults and have practically no residual effect. To achieve control the application must be repeated regularly. When these chemicals are used aphids are also effectively killed at the same time.

A few years ago a sudden outbreak of the leaf miner *Liriomyza solani* occurred on several holdings. This insect has existed for many years in tomato culture in Holland without causing economic damage. For unknown reasons it suddenly appeared in large numbers and, if no control measures are taken many leaves may be blanched, by the mining of the larvae, before the end of the season. An insecticide with a broad spectrum of action like parathion will kill this pest effectively. Application of parathion must be limited to the early stage of growth, as the interval between application and picking has to be fairly long. During the picking period only mevinphos and dichlorophos can be used, but as these only kill the adults, the same problem arises as with the control of white fly.

In tomato growing in Holland, an attack of red spider is seldom found and up to now it is only occasionally necessary to take control measures.

Lettuce

In lettuce production the pest and disease problem is really one of avoiding pesticide residues. Chemicals are available to give effective control, but, as the ratio between leaf surface and weight of lettuce is very high, accurate timing and limited dosages must be used to keep the recognized residue tolerances. The main diseases to be controlled are: Botrytis cinerea, Rhizoctonia, Sclerotinia minor and Bremia lactucae. In lettuce growing under glass downy mildew practically never occurs if the plants are free of the disease at planting out. The control measures have therefore, to be taken during propagation. For this purpose zineb dust is applied every five days from the moment the seeds germinate until the plants are planted out. The control of Botrytis and Rhizoctonia is usually combined. Before planting the soil is treated with 10 to 20 g quitozene (20 per cent a.i.) per m^2. Combinations of quintozene and dichloran or captan can also be used in this case. In the first weeks after planting out a thiram dust is applied once or twice as an extra measure to prevent any development of Botrytis. As an alternative, technazene smokes can also be used successfully. It is particularly necessary to take these control measures for the production of lettuce in late autumn and winter. Otherwise the risk of complete failure due to an attack of Botrytis and Rhizoctonia is considerable. In other words, the production of lettuce in that time of the year has only become possible thanks to the use of these fungicides.

Sclerotinia minor occurs only in certain restricted areas, especially on peat soils. It can be controlled successfully by relatively high dosages of quintozene (20 to 40 g of a 20 per cent dust per m^2) applied before planting.

Aphids need not be a problem in glasshouse production of lettuce. Applications of malathion, mevinphos or lindane smokes are very effective. Generally these insecticides need only be applied once or twice during the period that lettuce is usually grown under glass for no aphids are present in the open at that time and reinfection should not occur.

APPLICATION TECHNIQUES

Although special methods of application are possible in glasshouses, pesticides are still mainly applied by dusting or spraying. In lettuce growing, apart from smokes, only dusts are used. They are generally applied by a motorknapsack "sprayer". In cucumber and tomatoes production fungicidal dusts are used in the early part of the growing season and are mainly directed to preventative control. As soon as a pest or disease has become established, the grower switches to spraying, which is normally done by high volume equipment. To save labour there is an increasing interest in the use of other equipment including mist-blowers, foggers and electric evaporators, etc. All these methods have the advantage that the distribution of the chemical both through the house and penetration into the crop is very good. Pesticides used in this way generally lack persistence and consequently have to be applied more frequently than spraying. Research carried out at our Station during the last years has shown that some of the insecticides and mildew fungicides in use can be successfully applied by means of electric evaporators or fogging machines. Our aim is to carry out the whole control programme for a certain crop with the aid of this type of equipment.

Introduction of this apparatus into commercial practice is, however, still hampered by lack of suitable formulations and relatively high financial investment involved.

SESSION 4B

DISCUSSION

Mr. P. Wiggell: 1. Use of methylbromide against Phomopsis sclerotiodes - how effective is this treatment?

2. What is the cost of methylbromide application using motorised injector and how widely is this used in Holland?

Dr. L. Bravenboer: 1. Methylbromide proved to be ineffective against P. sclerotoides in both cucumbers and gherkins.

2. In Holland methylbromide is mainly used by motorised injectors. This is only done by contractors. The costs are about 2/- per square meter, including plastic sheets, labour etc.

Mr. D. Hitchman: 1. Not all chemical soil sterilants are liquid - dazomet for example is a powder.
2. I would challenge the remark that chemical sterilants should only be used where infection is slight.

Dr. L. Bravenboer: 1. In Holland only liquid soil sterilants are currently in use.
2. The effect of metham-sodium varies greatly from one place to another. For that reason it is only used if the infection is slight.

Dr. G. S. Hartley: As mushrooms are grown in a controlled environment with a forced ventilation system, it would seem possible to use the mechanism if attraction of the Phorid fly as a means of control. How much attention is being given to the insect behaviour and physics of this process which is much more important than the organic chemistry?

Dr. Hussey: Limited facilities in both manpower and materials have, up to now, prevented serious research on the striking control potential of this interesting situation. We are, however, hopeful that some work can be started in the not too distant future.

DISEASE PROBLEMS IN INTENSIVE CEREAL GROWING

E. Lester
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Summary In intensive cereal systems, diseases assume a major role in limiting yield. Foliage diseases assume a greater significance because of their effects on root production; in a system which encourages root loss from soil-borne disease. The need to control foliage diseases in intensive systems is more pressing than in rotational systems and reliance on resistant varieties is not satisfactory in the long term. Foliage disease control by preventing winter carry-over and by the use of fungicides has received too little attention in the past. Progress in these directions demands a more detailed knowledge of epidemiology than is available now. Success with continuous barley cropping is explicable in large part by the intervention of Take-all decline but with Take-all disease also, insufficient attention has been paid to the possible value of fungicides, particularly systemic ones.

There can be little, if any doubt in anyone's mind at this Conference, that disease is a major limiting factor in intensive cereal production. Pest problems, with the exception of Cereal Root eelworm, tend generally to diminish in importance as cereal cropping continues and manuring requirements tend to become more easily predictable, especially the need for nitrogen, as the rather unquantifiable effects of soil residues from non-cereal crops disappear.

The diseases which assume a particular significance in intensive cereal production are the foliage diseases and the soil borne diseases. As far as foliage diseases are concerned, a major obstacle in the way of providing solutions is the lack of information about their epidemiology. To some extent this lack of knowledge stems directly from reliance on resistant varieties as our sole weapon against them. As long as varietal resistance was a reasonably satisfactory method of control the lack of information was not felt, because the information was not necessary. Now that the weaknesses of this approach have been so clearly exposed and the need for other methods of control has assumed importance, the lack of this fundamental information is being felt acutely.

Another obstacle is the lack of reliable information about the effects of foliage disease on yield in practice. The normal sequence of events followed in attempts to provide this information is that disease level/yield relationships are established by experiments which are, naturally, designed specifically to avoid other sources of variation. Subsequently, field surveys are instituted to measure disease levels in practice and losses caused are computed by reference to the experimental results. These methods, although perhaps the best available with our present knowledge, have obvious defects. They ignore the fact that in real life diseases do not operate in isolation. Particular disease is merely one of very many factors, climatic, edaphic and ecological which are operating in concert on the crop, the pathogen and on crop/pathogen interaction. The assumption, implicit in the method, that the disease level/yield loss relationship is constant in all circumstances is clearly not justified.

Interaction between two or more yield - modifying factors leads to variability in yield effects of given levels of disease. Brenchley has demonstrated this clearly with his aerial survey technique.

Aerial photographs of cereal fields have shown areas of premature death, indicative of severe take-all attack, distributed in patterns over some fields. On-the-ground detailed disease surveys on these fields sometimes show little difference in take-all level between bad and good areas and only when an examination of soils is undertaken is the explanation for the distribution forthcoming. Severe disease expression is restricted to those areas where a given level of disease coincides with an adverse soil condition, where two factors each capable of restricting root production and function are operating together.

Other interactions are perhaps not so obvious. As an example, Last's work on barley mildew revealed the very significant fact, that the most pronounced effect of mildew infection was restriction of root growth. Similar effects have been shown to follow infection by yellow rust and it seems likely that this is common to all foliage diseases. This raises the question of the significance of foliage disease in intensive cereal production. One of the penalties of intensification is increased root disease and if, in addition, root development is restricted by foliage disease attack the resultant effect on crop yield will be far greater than the effect of the same level of foliage disease on an otherwise healthy crop. Control of foliage diseases - and naturally of any other controllable factor which restricts root development - becomes a much more pressing need in intensive systems than it is in rotational systems of cropping.

Control of foliage diseases has received little attention outside the use of resistant varieties. The mechanism for resistance to cereal pathogens that is available to the breeder is that carried by major genes and introduction of resistance of this type, conferring virtual immunity to specific physiologic races, exerts extreme selection pressure on the pathogen which responds with alacrity by "producing" a new race. It is now generally accepted that resistant cultivars are unlikely, because of this plasticity of pathogens, to maintain their advantage for more than about three years commercial use. This calls for a modification in the approach of the breeder and the expenditure of time and effort on the incorporation of field resistance, such as that exhibited towards Yellow Rust by Cappelle Desprez, commends itself. I have no doubt, even as a layman, that this is far easier said than done. The difficulties are great - it is to be hoped they are not insuperable.

Events of the last few years have emphasised the danger of relying solely on resistance to control these diseases. We have lost one of the highest yielding varieties of winter wheat ever offered to British farmers, to the new race 60 of yellow rust, namely Rothwell Perdix. Fortunately its breakdown was so rapid and complete that it was lost before it occupied a significant proportion of our wheat acreage. Its sister varieties Tadorna and Ibis led to much more serious loss in the Netherlands where together they occupied some 60% of the acreage and suffered the same fate. In spring wheat the picture is perhaps rather worse. The variety Opal, a considerable advance on previous varieties in yield potential, occupied some 70% of our acreage in 1966 when it was severely attacked by race 3/55.

The spring barley outlook is no better. Every one of the mildew resistant varieties we have, with perhaps the exception of Sultan, has broken down and even this variety was slightly affected in variety trials in the South East this year.

Prospects for resistance to <u>Rhyncosporium secalis</u> in barley are not promising. Already more than one race of the pathogen has been recognised and it threatens to be just as 'plastic' a pathogen as the others referred to, equally capable of meeting resistance with a change in race.

In the face of the apparent inevitability of this process of disease → resistant variety → change in pathogen → breakdown of resistance, it is imperative that other means of control should be examined and exploited to the full, not as a substitute for a breeding programme but as a necessary supplement to it.

Consideration of the epidemiology of foliage disease of annual crops leads one to examine two possible points of attack, both of which may in cereals be breached by chemicals - either fungicides, or herbicides or both. These are carry-over from crop to crop and modification of the progress of the epidemic during the life of the crop.

In any season the degree of attack by foliage diseases is a function of inoculum available to the crop, crop condition and climate. Since we have no control of climate, effort must be concentrated on the other facets. Crop condition, in regard to such factors as sowing date, density, nutritional status and so forth, clearly influences the development of different diseases in different ways - e.g. early sowing encourages leaf blotch, but tends to reduce mildew in spring barley and vice versa. Susceptibility of wheat to attack by yellow rust and Septoria spp. is increased by high nitrogen status in the crop, but the penalty for keeping a crop short of nitrogen is likely to be as great, perhaps greater than that imposed by disease. Thus the husbandry techniques applied to a crop must of necessity be a compromise and suggestions or advice about treatment are concerned mostly with what should have been done and are generally offered only with the benefit of hindsight.

The problem of inoculum is not easily assessed. Fortunately the specificity of pathogens which presents such a problem to the plant breeder, is of assistance in the present context in that it is clear that one crop species does not generally constitute a threat to another. One is therefore concerned with (a) disease carry-over from harvest to sowing of the same species in the same field (b) the significance, over what distance, of inoculum from other fields and (c) the influence of the overall level of survival in an area on the development of widespread epidemics.

Evidence about the relative importance of these three factors is difficult to come by but I suggest that survival within fields is not only of primary importance; it is an aspect which is in the hands of the farmer to control to some extent. Furthermore, successful concerted effort on the within-field problem will automatically reduce the problem posed by the other two factors.

Literature on the duration of survival is scant. The volunteer plant is a potent source of infection and this can easily be seen by field observation during the early life of the sown crop. Prevention or eradication of volunteers is the prime aim for reducing inoculum of such obligate parasites as yellow rust; it will also reduce survival of other leaf pathogens, while leaving unsolved the question of survival on debris. What information is available suggests that mixing debris with soil substantially shortens the period of this mode of survival.

Stubble cultivations can perform both these functions adequately, provided soil conditions allow. Normally at least three cultivations are required and frequently the last of these, on difficult soils or in wet autumns, is not achieved. In these circumstances chemical treatment with a total herbicide may provide an effective substitute for cultivation. Use of herbicides as substitutes for earlier cultivations is not so effective, judged by the results of preliminary trials, perhaps because dormant seeds are not encouraged to germinate by herbicides as they are by mechanical disturbance. It is possible that the use of dormancy breaking chemicals and also perhaps of eradicant fungicides could find a place in these operations but before search for such materials is justifiable, evidence of the effectiveness of this whole approach will be required and this is at present lacking.

Investigations now under way in Sussex will, it is hoped, provide some information on the possible value of this approach. Here, a group of farmers have agreed to concentrate on stubble cultivations with the specific object of reducing disease carry-over in barley to a minimum. Chemical treatments will be applied to supplement cultivations and a determined effort is being made to ensure efficient burial of debris by careful ploughing before the end of November. Furthermore these same farmers have agreed among themselves that no winter barley will be sown in the area. By these means it is hoped that opportunity for disease carry-over will be severely restricted and any epidemic which might arise in 1968 will thereby at least be usefully delayed if it is not entirely prevented.

Even if all internal sources of infection are removed, crops are nevertheless open to invasion by airborne spores, of some diseases at least, from remote areas such as Continental Europe and North Africa. The outstanding fully documented instance of this is black rust. Overwintering infection rarely if ever occurs in the U.K. but the disease nevertheless occasionally reaches epidemic proportions, particularly in the South and West of England. The origins of these epidemics have been identified as air masses carrying uredospores of the fungus from countries such as Spain, Portugal and Africa, arriving over our south coastal areas and depositing thereon their spore-load. Hurst (in the press) has demonstrated conclusively that opportunities for similar movements of spore-bearing air masses occur, in some seasons frequently, between the U.K. and central and northern Europe and could account for outbreaks of yellow rust and perhaps other diseases. For this reason, and because it will be in practice be virtually impossible to achieve eradication of all internal infection sources, attention should be paid to the problem of delaying or reducing disease spread during the life of the crop; my second point of attack. The question of applying fungicides to cereal crops has largely been ignored in the past, partly on the grounds of cost and partly on the grounds of practicability. It has been thought that control of foliage disease would of necessity require fungicide applications on several successive occasions and that the later applications would be required at a time in the life of the crop when resulting damage would outweight the benefits of treatment.

This attitude has perhaps been unwittingly fostered by experimental work primarily designed to relate yield loss to disease levels, in which, to achieve satisfactory control for this purpose, fungicidal sprays have been applied at fortnightly intervals (sometimes even weekly) until the time of earing, usually by hand or knapsack sprayer in order to avoid damage. Is it necessary for practical purposes to go to these lengths?

The typical progress curve for a foliage disease epidemic is a sigmoid one, whose angle of slope varies according to the speed of development of the epidemic. This is well illustrated by Potato Blight and in this case control is achieved in one of two ways. Either the whole curve can be displaced later in time by sprays applied in the very early stages of the epidemic, or the angle of slope can be modified in some instances by sprays applied after the disease has become visible in the crop.

There may well be a parallel in the cereal crop in that shifting the whole curve later in time might be achieved by fungicides applied early in the epidemic. Success with this approach has recently been reported from Switzerland and the Netherlands, single sprays of a nickel/dithiocarbamate mixture to wheat at 1 percent yellow rust infection having delayed progress of the epidemic by 12-14 days. In one trial in 1966 (Zadoks - personal communication) this delay resulted in a 50 percent increase in yield. Yield increases of this order are likely to follow fungicide applications only when the epidemic is severe and the economic use of fungicide applications - indeed the decision whether to apply fungicides at all, depends basically on accurate disease forecasting. This in turn demands accurate weather forecasts and, once again, more knowledge of epidemiology, together with more precise information, each year, about sources of infection, their distribution and the amount of inoculum available. Success will therefore not be achieved quickly or easily. At present, cost of materials and of application in relation to returns from cereal production will themselves dictate that fungicides are used only in need. Even if substantially cheaper materials do become available, sufficiently cheap to warrant their use as 'insurance' sprays, this does not obviate the need for effective forecasting systems to be developed, since indiscriminate use of chemicals irrespective of need is undesirable in any case. There is evidence of increasing interest and activity in the field of fungicides for cereals on the part of fungicide manufacturers. This must be accompanied by increased interest and activity in the field of cereal disease epidemiology on the part of researchers and advisers if progress is to be achieved at the rate required. This field has been neglected for too long and there is much lost ground to be made up.

There are two other diseases which have a considerable bearing on crop production in intensive cereal systems. These are eyespot caused by Cercosporella herpotrichoides and take-all, caused by Ophiobolus graminis. In most respects eyespot is closer in its behaviour to the foliage diseases than to soil-borne diseases. Although perpetuated on stubble and to that extent soil-borne, epidemic development of the disease is dependent greatly on weather conditions. It has been regarded as a disease of autumn-sown cereals, those sown in spring benefiting from a disease - escape mechanism. Severe attacks do, however, occur on early-sown spring crops, especially spring wheat when, as in 1967, we get an extended cold wet Spring. This year widespread infection has been recorded on spring barley also, but its significance as a disease on this crop has yet to be determined. One consequence of intensified cropping, with emphasis inevitably on spring-sowing because of disease risks, is the pressure on machinery and labour to complete sowing operations in the time available. The pressure is further increased by the need to make maximum use of machinery, depreciation on this being a major factor in production costs. The trend arising from this is a wider spread of sowing date, both earlier and later and the proportion of the crop which can benefit from disease escape is reduced. There is clear need therefore, to determine the significance of eyespot to the spring barley crop.

One aspect of eyespot worthy of further consideration is the use of growth regulators to control eyespot lodging in winter wheat. Their use as a precautionary measure is hardly justified at our present state of knowledge though it may eventually enable the sowing of eyespot susceptible varieties of high yield potential in eyespot situations. Continental experience suggests that precautionary use of such a material, with the implication it carries of needless spraying, may not be necessary. It has been shown that eyespot assessments carried out in late April can be utilised to determine the need for spraying and that applications made as late as G.S. 6-7 can be effective in preventing eyespot lodging. 25 percent tillers infected at the end of April is taken as indicative of the need to spray. These results require confirmation under U.K. conditions and a clearer understanding of side-effects of these materials is required before general recommendations could be made. I refer to increased susceptibility of winter wheat to yellow rust and Septoria spp. in some instances where chlormequat has been used. It is of interest that in over 100 experiments done in Holland on control of eyespot lodging with this material, only in three did the increase in foliage disease outweigh the beneficial effects consequent on reducing lodging.

After earlier comments on the value of breeding for resistance to foliage disease it should be made clear that the same does not hold for eyespot. In the variety Cappelle Desprez we have the very valuable character of eyespot tolerance and this feature is responsible in part for its popularity. Even after 15 years, it still accounts for 79% of the winter wheat acreage in Britain. This kind of tolerance, in which the host plant becomes infected but resists the worst consequences of infection, does not exert great selection pressure on the pathogen and is therefore less liable to breakdown.

For the major problem confronting the intensive cereal grower, namely take-all, no sources of resistance or tolerance have yet been found in wheat or barley, nor has the successful use of fungicides been demonstrated, beyond small scale soil fumigation for investigational purposes. Some years ago a replicated trial using a wide range of soil fungicides was done in Hampshire, the results of which were discouraging to say the least. There may now be other fungicides worthy of trial and this approach must not be forgotten because of current failure. It is patently obvious that an effective systemic fungicide, available at low cost (preferably perhaps in the form of a seed-dressing) and with no or negligible side-effects would be of inestimable value - both to the farmer and its discoverer. Pending this take-all Utopia, reliance must be placed on that favourite among Pathologists' dicta "learn to live with the disease".

The traditional pattern of take-all development, typified by increased disease with increasing numbers of susceptible crops, still holds good for short sequences of susceptible cereals interrupted by 'break' crops of non-susceptible species. This pattern of disease development led one to expect consistent and continuing crop failure following the initial severe disease attack.

Slope and Cox drew attention to the inaccuracy of this assumption, pointing out that with continuous winter wheat cropping beyond the point of failure due to take-all attack, far from increasing in severity, the disease in fact declined, with an accompanying increase in yield. Extension of this work undertaken at Reading will be described by Shipton later in this Session.

Academically the phenomenon is of considerable interest, presenting as it does a unique example of a naturally imposed biological control of a soil borne pathogen. Practically it is of considerable import as a major factor in successful barley monoculture on chalk soils at least and probably on others. Furthermore, recognition of the fact of take-all decline calls for a re-appraisal of the role of 'break' crops in intensive cereal production. 'Break' crop trials at Rothamsted have demonstrated, over several years, that the beneficial effect of a one-year 'break' is effective for only one following crop and that subsequent crops show a higher level of take-all attack and lower yields than continuously-grown crops. The benefit of the 'break' crop to the whole ensuing cereal sequence is therefore substantially less than would be expected when judged solely on the basis of yield increase in the first crop after 'break'.

Further than this, the control of take-all and consequent yield increase in the first crop after 'break' is by no means always achieved. Success depends fundamentally on the absence of host plants for take-all during the year in which the 'break' crop is grown. This calls for complete control of both stoloniferous weed grasses and of volunteer cereals and it is not every farmer who appreciates this nor is it every 'break' crop that provides opportunity for ensuring it.

Perhaps the commonest offender is the undersown ley, or grass seed crop which provides no opportunity for control of these carriers at all and this in itself may be the reason why the value of one year grass as a 'break' is so often called in question. The grass crop is not the only offender - how frequently does one see a moderate crop of cereals in the bean 'break'? Appreciation of this aspect of 'break' crops should lead to more strenuous attempts at weed control and to consideration of both cultivations and chemicals as indirect aids to disease control.

Apart from the side effects of 'break' crops on disease-carrier survival, the common assumption that all 'break' crops are equal in their ability to control take-all is open to question. Rothamsted results suggest that, in some seasons at least, oats allow measurably greater survival of take-all than do beans. This may be because the fungus is supported on the roots of oats, as runner hyphae, without causing root lesions. Certainly it is frequently possible to find runner hyphae of Ophiobolus on oat roots, but to the best of my knowledge these have never been tested for pathogenicity to wheat or barley. A more complicated question involves a suggestion from work in the Netherlands that 'break' crops, performing similarly in respect of take-all itself, may have different effects on take-all decline by interfering to different degrees with the microbiological status of the soil, believed to be responsible for take-all decline. Thus fallow and flax as 'breaks' in the cereal sequence, while producing the same yield response as other 'break' crops in the first wheat crop following, failed to show the same yield depression in subsequent crops, indicating their ability to preserve to some extent the decline status of the soil. This facet of the 'break' crop problem warrants further investigation.

Most of the initial experimental work on take-all decline was done with winter wheat. At Reading our main effort has been directed towards spring barley, one of our objects being to discover, if decline develops under barley cropping, whether this is operative for subsequent cropping with winter wheat. Experience with winter wheat shows that the effects of take-all in the years of peak disease, before the benefits of decline are apparent, are so crippling that it is a brave man who will continue wheat cropping, even if the farm economy will stand it. The effects of take-all on barley on the other hand are not nearly so severe and an economic yield can often be obtained from this crop in spite of the disease. This leads one to consider the possibility of bridging the years of peak disease with the low response crop, barley, and subsequently utilising the decline phenomenon to revert to winter wheat cropping without the 'break' crop which on past experience would be deemed essential. An approach such as this, if successful, offers an attractive prospect for the continuous barley grower. At present the all-barley grower who wishes to introduce autumn-sown wheat for various reasons (many would like to do so) can only be advised to introduce a 'break' crop in preparation for winter wheat, which automatically limits his wheat acreage to the acreage of 'break' crop he can grown and sell economically. For such a farmer both the choice of 'break' crop and the acreage he can grow is limited. The alternative suggested above is tentative in the extreme. Indications from the limited amount of work done on this aspect of take-all are that decline does develop under continuous barley cropping and that it is valid for the wheat crop also. Much more work needs to be done before it can be accepted as generally applicable but it has been the basis of advice in a very few instances during the last two years. Farmers given this advice and others who have offered to test the feasibility of growing wheat after several years of barley, have been selected with care for their ability as cultivators and husbandmen. Such a system will not allow errors of husbandry, which might be acceptable in the healthy crop, without serious yield losses.

It should be made clear, finally, that intensive systems of cereal production will not, on present evidence, give high yields. That they can give satisfactory yields is clearly demonstrated, but only when a high standard of crop husbandry is applied. Again on present evidence, the choice of system appears to lie between rotationally cropped high-yielding cereals occupying not more than 50 or 60 per cent of the arable acreage on the one hand and continuous cropping on the other. The so-called "happy mean" - in this context partial intensification to something of the order of 80-85% cereals - is a most unhappy mean. It goes almost without saying that this assessment of the situation will only be valid as long as production costs can be held to a reasonable level below returns. At the present rate of increase in production costs, if this continues, it is difficult to forecast anything other than the end of continuous cereal production within the next few years. Meanwhile the biology of the system will I hope be a little better understood and by that time, perhaps, as I sincerely hope, there will have been a break-through in the fungicide field.

EFFECT OF INTENSIVE CROPPING ON THE PESTS OF CEREALS

IN ENGLAND AND WALES

by Robert Gair

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SUMMARY

Intensive cropping of cereals in England and Wales has so far led, not to an increase in the frequency and importance of pest attacks, but to their general decline. Reasons for this are advanced. An exception is the cereal-cyst nematode Heterodera avenae, which is damaging on certain light soils.

Two opposing viewpoints are held regarding the importance of pests under systems of intensive cropping. One is that monoculture leads to an increase in pest density - an obvious example is the rise in importance of the potato-cyst nematode, Heterodera rostochiensis, in those areas of the country where potatoes have been cropped too closely.

The second view, that pests do not necessarily increase with monoculture, is implied by W. E. H. Fiddian in his recent paper entitled "Cereal growing in the seventies". The cereal crops on his hypothetical Friday Farm are quite unaffected by insect or other pests, and indeed the only pathogen still troubling cereals is take-all disease.

Which of these two views is correct? The evidence obtained from advisory work, and from surveys of fields growing cereals either intensively or continuously for many years, suggests that Fiddian's optimistic view is the more accurate. The complex of insect and other pests continue to fluctuate at low levels on fields of a wide variety of soil types on which cereals are grown intensively. Pest damage to cereals is considerably less in such fields than in those farmed more traditionally on a system of alternate husbandry based on the grass ley. Reasons for this general decline in pest importance with the rise in intensive cereal cropping are advanced below.

1. Of some 58 insect, nematode and molluscan pests of cereals listed in the Ministry's bulletin (Anon, 1965), 33 can be classified as ley pests; that is, they normally inhabit grassland and attack cereals which follow infested grass in the rotation. Ley pests include some of the most economically important organisms such as wireworms, leatherjackets, slugs, moth caterpillars, frit fly and maggots of other dipterous flies. By removing the grass break from the rotation, the threat of pest attack is thus greatly lessened.

2. A second group of pests depend on neither grass nor cereals for oviposition sites. The chief pest here is the wheat bulb fly, Leptohylemyia coarctata, which is important on winter wheat and barley following summer fallows, vining peas or root crops. Attacks on wheat after wheat are extremely rare and are unknown in a sequence of spring barley crops.

3. The third group of pests spend virtually the whole of their life-cycle on cereals, and it is from their ranks that the threat to intensive cereal cropping should come. However, such pests as cereal aphids, cereal flower midges, cereal leaf miners, gout fly and flea beetles are no worse in a cereal crop following cereals than in a cereal following a 'break' crop.

It is true that the cereal-cyst nematode, Heterodera avenae, can build up to damaging proportions under intensive cereal cropping, and yield losses of up to 10 cwt/acre of spring barley have been accredited to this pest (Collingwood, 1967). Although H. avenae is widespread in England and Wales (Southey, 1956), its effects are probably important only on a proportion of fields on light-textured soils, notably the chalklands in the south of England.

Saddle gall midge (*Haplodiplosis equestris*) attacks have increased in recent years in parts of England, and present methods of cereal harvesting certainly favour the buildup of this pest. Whether it will continue to increase in numbers is probalematical, and its status as an economic pest has yet to be evaluated under English conditions.

4. A number of pests, such as the European corn borer (*Ostrinia nubilalis*) and Brighton Wainscot moth (*Oria musculosa*), are important in some intensive cereal growing areas of continental Europe, but apparently reach the north-western limits of their range in those counties of England which border the English Channel.

5. On most farms in this country, intensive or continuous cereal cropping refers to spring barley, which is either immune from or tolerant towards so many pest attacks.

That pests shall continue to be of little importance on intensive cereal growing fields depends on a number of factors.

(a) Spring barley must continue as the favoured cereal, for a shift to spring wheat or oats could easily bring a number of pests such as C.R.E. and stem eelworm (*Ditylenchus dipsaci*) into greater prominence.

(b) Farmers must pay great attention to their husbandry techniques; in particular, the early and complete control of grass weeds in cereal stubble is essential, for such weeds provide attractive oviposition sites for Tipulid flies, moths and slugs.

(c) Intensive cereal growing ought to be limited to those areas and fields which are of sufficiently high fertility to support the practice. So many fields on thin, light-textured soils are quite unable to maintain high cereal yields, and it is often on these fields that cereal pests are prevalent.

(d) New techniques for growing cereals intensively must not tilt the balance in favour of pest attack. Chemical ploughing, slit seeding or the adoption of single tillering cereal varieties may allow a pest population, at present economically unimportant, to become a limiting factor in no small degree.

Finally, it is well to remember that the ecological setup in a situation where cereal follows cereal over a number of years is one of dynamic balance. Over England as Wales as a whole, the proportion of cereals to grass will remain small, and many pests which normally inhabit grassland are sufficiently mobile to affect cereal crops growing some distance away. And we must always anticipate changes in animal behaviour which intensify pest damage; sparrows can now be found stripping cereal heads in the centre of fields, when a few years ago they only worked the headlands of fields close to towns. The parallel between this occurrence and the quelea bird menance of Africa sounds rather far-fetched, but at least it means that the farmer and agricultural zoologist have no cause for complacency.

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SESSION 5A

DISCUSSION

Mr. J. D. Wafford: As couch grass (Agropyron repens) is extremely difficult to control with direct-drilling and is a major source of innoculum of Ophiobolus graminis, would it not be better to abandon direct-drilling and use cultivation techniques for the eradication of couch?

Dr. D. H. Brooks: I did not claim that paraquat controls couch well. In our direct-drilling trials where couch was absent, we had a marked reduction of take-all. In some winter trials where couch was present, direct-drilling also reduced take-all. In our spring trial, however, the carry-over of disease on the couch outweighed inherent reduction due to direct-drilling. We would not recommend direct-drilling on sites where couch is a problem because of the failure of paraquat to achieve sufficient control.

Dr. W. Berg: May I ask Mr. Catling to repeat the corrected toxicity data for the new compound N.2790?

Mr. W. Catling: Corrected toxicity data for N.2790:

Acute oral LD_{50} Male Rats 7.94 mg/Kg. and not 16.5 mg/Kg.

Acute dermal LD_{50} Albino Rabbits 147 mg/Kg. and not 35 mg/Kg.

Mr. J. D. Newman: In the work which has been done on the wildlife testing against birds of new organophosphorus compounds for the control of wheat bulb fly, has any comparison been made with the standard aldrin seed dressings in comparable experimental conditions?

Mr. H. J. Terry: No, we didn't include dieldrin in our wildlife studies. As Mr. Newman knows, commercial firms are restricted in the scale of wildlife studies that can be carried out and in last year's work we were guided mainly by the suggestions laid down in Working Document No. 4. All we were able to show was that ethion was unlikely to cause sudden serious effects on wildlife.

This year we are doing a much larger field study and it may well be that we should include comparisons with dieldrin. Perhaps any members of the Wildlife Panel who may be present may like to comment.

Dr. H. C. Gough: Mr. Gair implied that migratory nematodes were unlikely to build up to serious proportions under intensive cereal cropping. Although he was speaking particularly about species of Pratylenchus and other genera associated with grasses, what information have we about other species or genera?

Mr. R. Gair: Population studies have shown that for many species of migratory free-living soil nematodes, largest increases in numbers occur under grass, and the increases are a good deal smaller under cereals. Whether or not some species can build up to damaging proportions under a run of cereal crops is at present a matter for conjecture.

Dr. H. C. Gough: I wonder if Mr. Collingwood was quite fair to the N.A.A.S. work on the relationship of cereal cyst nematode populations to yields of barley which he dismissed rather briefly. The technique has limitations though it worked efficiently for potato cyst nematode. However, the lack of any apparent effect of eelworm on barley yields was so striking that one feels that other unknown factors could be involved.

Mr. C. V. Dadd: While on the question of nematodes would Mr. Collingwood be prepared to say anything at all about the kind of resistance exhibited by the variety Kron?

Mr. R. Gair: At one time Kron barley was bracketed with the other Danish varieties Drost, Alfa and Fero in having partial resistance to Heterodera avenae. It is now apparent from British and Dutch experience that Kron differs from the other three varieties in that its resistance is stronger, covering both major British pathotypes. Any genetical differences to account for this have not been elucidated.

Mr. W. T. Cowan: May I ask Mr. Lester's views on the possibility of reducing incidence of eyespot infection by soil applied herbicides pre-emergence of crop through alterations to the micro-climate during the critical period of ascospore discharge? Dr. Cunningham's work in Ireland has indicated control in this way achieved by delaying spring sowing by two weeks.

Mr. E. Lester: As far as I know, there is no evidence that herbicides have any direct fungicidal effect on eyespot. There is evidence that later sowing reduces eyespot infection, but whether this is due to the opportunity for better weed control or whether it is due to the beginnings of the disease escape mechanism which we recognise in the spring crop, I don't know. There is a point, however, which emphasises the importance of weed control and this is the effect of micro-climate around the base of the plants in the spring. It has been shown that this is a critical factor in the development of an eyespot epidemic.

Dr. D. H. Brooks: May I add a few comments to Mr. Lester's answer. Last year we carried out a number of stubble cleaning trials with paraquat on wet sites. In several of the subsequent crops we noticed a marked reduction of eyespot where paraquat had been sprayed and this, in each case, was associated with extensive growth of Poa trivialis in the unsprayed areas. The decrease in eyespot in the sprayed areas could be due to a less humid micro-climate in the spring.

Mr. W. T. Cowan: Mr. Gair mentioned complete control of perennial grass weeds in cereal stubbles as desirable for the control of many potential pests. This is the problem of greatest moment in herbicide development and certainly the most difficult one. If he can contribute in any way, this would be most welcome.

Mr. R. Gair: The early control of grass weeds in the cereal stubbles seems to be the key factor in maintaining high yields in intensive cereal growing. This is because of the effects of grass weeds on diseases, pests and the effect of direct competition with the cereal plant. Those farmers who have been most successful in growing continuous cereals attribute their success largely to the fact that they cultivate their cereal stubbles immediately after harvest and ensure that grass weeds are controlled.

Dr. A. E. W. Boyd: Have any observations been made on the incidence of Cephalosporium leaf stripe of wheat in the continuous cereal programme?

Mr. E. Lester: Our experience in the south-east is that in those few cases where we have had serious trouble from Cephalosporium leaf stripe, this has been associated with alternate husbandry systems and has been restricted to the first one or two crops after grass. My impression is that it will not become a problem in intensive cereal culture. I would like to ask Dr. Brooks whether he has any observations on this disease as it affects the minimum cultivations trial at Jealott's Hill.

Dr. D. H. Brooks: In 1966, which was the year I was introduced to this disease, I was surprised to find a very high level of infection in the non-ploughed plots. The ploughed plots also showed some infection. In 1967, the disease, although present, was of no serious consequence. I am still puzzled about where it camefrom and also where it went.

Mr. C. Kinsey: I would like to ask Mr. Lester whether he considers that heavy seed rates have an influence on the severity of take-all and eyespot.

Mr. E. Lester: I think there is abundant evidence that plant density does influence the development of both these diseases. Dr. Garrett has dealt with the take-all aspects of this situation and Dr. Mary Glynne with the eyespot aspect. In the case of take-all the problem is one of inter-plant competition while with eyespot it seems likely that the greatest effect of high density of plant is on micro-climate.

Sir Harold Sanders (through Mr. C. V. Dadd): Is the reduction of take-all with direct-drilling due to soil compaction and, if so, could earlier compaction help?

Dr. D. H. Brooks: Compaction of soil in the spring (by rolling) has been known for many years as a measure which gives partial control of take-all, probably by increasing the level of carbon dioxide in the soil air. *Ophiobolus graminis* spreads over the surface of wheat roots, where it is prone to carbon dioxide damage.

In the case of direct-drilling, I don't think soil compaction is important, but I think carbon dioxide is. After drilling, ploughed soil is obviously less compact than direct-drilled soil, but from the few measurements available, in the spring this is no longer true. Frost causes decompaction of the soil, and rain subsequently re-compacts the ploughed soil more than the direct-drilled soil. Therefore, the higher levels of carbon dioxide measured in direct-drilled soil is due, not to compaction but to greater production in the soil. This comes from the higher microflora and numbers of arthropods supported in the direct-drilled soil.

Since take-all spreads very slowly until soil temperatures start to rise in about April, I don't think compaction earlier than this is likely to be more effective.

Dr. M. J. Geoghegan: There are very sound reasons for thinking that stubble hygiene can make a worth while contribution to the control of certain cereal diseases, but I feel it must be 100 per cent effective; therefore I think that the use of a herbicide, like paraquat, which eliminates all green tissues, would be far more effective than cultivations.

THE VALUE OF ERADICANT TREATMENTS FOR THE CONTROL OF APPLE MILDEW AND APPLE SCAB

by R.T. Burchill
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INTRODUCTION

The control of apple tree fungus diseases is based largely upon one of three methods of which the most common is protective spraying. This involves the regular application of chemicals to the developing foliage and fruit and attempts to provide a complete fungicidal cover of susceptible tissues, thereby preventing the germination of spores subsequently deposited upon these areas.

The second method used mainly in the control of apple scab (Venturia inaequalis) is curative spraying (Storey and Ives, 1956). Information on the climatic requirements necessary for the release of spores, their dissemination, deposition and germination led to the development of a forecasting system which indicated the periods when infections were most likely to occur (Mills and La Plante, 1951, 1954). Meteorological instruments are able to determine when infection requirements have been satisfied and hence the advisability of immediately applying a fungicide able to destroy germinated spores.

The third method is eradication or the destruction of established fungal infections. Little work has been done with chemicals in this field, possibly because of a lack of suitable materials, but eradication by the mechanical removal of diseased tissues such as branches infected with European canker (Nectria galligena) or shoots infected with apple powdery mildew (Podosphaera leucotricha) has been a common practice for many years.

Total eradication is the ideal solution to the disease problems confronting fruit growers; unfortunately, however, where a disease is indigenous its complete destruction presents problems which are often insurmountable. Nevertheless, partial eradication involving the destruction of a high proportion of the pathogen or the eradication of a particular phase in its life history, such as conidiospore production, invariably facilitates subsequent control measures. Suppression of spore production at a time when the host plant is producing susceptible tissue enables the plant or its fruit to escape infection (Burchill and Edney, 1963).

An illustration of the improvements that may be obtained in the control of two of the major diseases of apple by an approach based on eradication and/or suppression of spore production is provided by recent work on apple mildew and apple scab.

Apple Mildew

In a relatively short period the incidence of apple mildew has increased until it is now a disease of major importance within fruit-growing areas in this country. This increase may be attributed to a number of factors including the replacement of sulphur sprays by chemicals possessing little fungicidal activity against mildew and the omission of dormant season sprays of DNOC/petroleum oil (Moore and Bennett, 1959). Possibly the most important single factor however, has been the change in pruning practices from the spur to the renewal and regulated systems. Apple mildew overwinters within vegetative and fruit buds infected during the preceding summer. In the spring the fungus present within the bud rapidly envelopes the emerging shoot, leaf and blossom tissues with mycelium. These infections constitute the 'primary infection phase'. Conidiospores originating from this source are responsible for the spread of the disease to healthy tissues where they produce 'secondary infections'.

Terminal buds are the most important sources of primary infection as they form extension shoots capable of producing millions of spores. A high incidence of primary infections in early summer results in the production of enormous numbers of spores; consequently a high standard of disease control must be maintained if no spores are to reach unprotected foliage. The eradication of this perennating source and the resultant reduction in conidiospore numbers would greatly improve the chances of the summer spray programme effectively controlling the small relic inoculum.

Eradication by pruning

Under the spur system of pruning most extension shoots and hence infected terminal buds were removed and consequently the spring inoculum concentrations were low and easily controlled. The change to the renewal and regulated systems resulted in the minimum removal of wood and although obviously diseased buds and shoots were cut-out, terminal buds infected at the end of the growing season and therefore unaffected in external appearance escaped detection (Burchill, 1960). As a result, a large amount of overwintering mildew persisted on the tree and year by year this level has progressively increased.

The effect of this change in pruning systems on the amount of perennating mycelium was demonstrated in an experiment carried out on an orchard of the apple variety Cox's Orange Pippin (Burchill, 1960). In this trial a group of trees was renewal pruned and compared with another group which received similar pruning plus the removal of the first inch of all shoots over six inches in length. In both groups all visible mildewed shoots and buds were removed. Assessment of the number of primary infections in the summer following treatment showed that on trees receiving the additional 'shoot tipping' the level of primary infection had been reduced by 80-90%. Most of the infection that remained originated from shoots less than six inches long which had not been 'tipped'.

Eradication by the removal of diseased tissues had reduced the level of overwintering infection and therefore fewer spores were available in the following spring.

The importance of the overwintering inoculum concentration to the development of the disease in the summer

The amount of inoculum available in the early summer largely determines the number of secondary infections that follow. Estimations of the total weekly concentrations of conidia present in the atmosphere during the summer, and the relationship between these concentrations and the numbers of secondary infections developing later, demonstrated that inoculum concentrations reached a peak in late May, early June, followed two weeks later by a high incidence of secondary infections (Burchill, 1965). The inoculum for this peak originated from infected extension shoots (primary infections); therefore had the tips of these shoots been removed during the winter the subsequent high spore concentrations would not have occurred.

The improvement in tree cropping resulting from the renewal and regulated systems of pruning has meant, however, that this method of eradication is used with reluctance. Ideally a chemical able to destroy the fungus present in the dormant bud, or possibly a chemical applied in late May which would suppress spore production and so prevent the rapid increase in inoculum, would provide a solution to the apple mildew problem.

Apple scab

The improvement that may be obtained in disease control by an eradicant approach based on chemical sprays is demonstrated in recent work on apple scab.

Venturia inaequalis overwinters by means of perithecia formed in diseased leaves present on the ground. In the spring ascospores are ejected from the mature perithecia and disseminated by wind to susceptible tissues where, given suitable climatic conditions, they establish infections. A break in the life cycle of the disease obtained by eradication of the perithecial stage would eliminate ascospores in the following spring, and as there would be no new infections summer scab sprays would be unnecessary.

The first reported attempts to eradicate perithecia met with limited success (Keitt and Palmiter, 1937) and it was not until 20 years later that Hutton (1954, 1957) working in Australia was able to demonstrate the improvement in disease control that could be obtained by chemicals applied specifically for this purpose.

In these experiments a single spray of 0.1% phenylmercuric chloride (PMC) was applied to the trees after harvest but before leaf-fall. This spray prevented perithecia formation thereby interrupting the life cycle of the disease. In certain well isolated orchards the reduction in ascospore numbers in the spring following autumn treatment was such that routine anti-scab sprays were no longer necessary, whilst in other less well isolated orchards the number of spring and summer spray applications could be reduced.

In 1963 several experiments were carried out in England to study the value of this eradicant approach to the control of apple scab (Burchill and Hutton, 1965); the most successful treatment consisted of 0.05% PMC applied in the autumn (post-harvest/pre-leaf-fall) followed by an application of 0.01% PMC just before bud-burst. The two sprays were sufficient to reduce the level of scab, assessed as the number of lesions per 1,000 spur leaves, from 405 on the unsprayed section to 3 on the treated area, a reduction of 99.3%. No anti-scab sprays were applied to the assessed trees during the spring and summer.

In designing this trial, it was proposed initially that only the autumn treatment would be applied; owing to the size of the trees, however, the highest branches were inadequately sprayed and as a result many of the leaves escaped treatment. This was later confirmed by ascospore productivity tests which showed that on leaves collected in December following treatment, many more ascospores were produced from leaves sampled from the upper branches of the tree than from the lower branches, whereas leaves collected from similar positions on unsprayed trees gave almost identical counts. Because of this poor coverage 0.01% PMC was applied just before bud-burst to the apple leaves on the ground. A spray at this concentration has been shown to restrict the release of ascospores from mature perithecia (Hutton and Burchill, 1965).

The almost total absence of scab following the two sprays suggests that the double application may be sufficient for effective scab control in isolated situations. Later experiments (Burchill, 1966) indicated that 0.02% PMC may be equally as effective as 0.05% PMC.

Even in experiments where the dormant season spray did not totally eradicate the fungus, the treatment nevertheless reduced the concentration of ascospores to an insignificant level so that relatively few new infections developed.

Laboratory assessment of the sporing potential of treated and non-treated leaves in the spring showed that the ascospore concentration per cm^2 of leaf was 41 from leaves sprayed with 0.05% PMC compared with 3,136 from unsprayed leaves, a reduction of 98.7%. No ascospores were recorded from leaves which received both the autumn and pre-bud-burst mercury sprays.

Inoculum concentration

In one series of experiments with dormant season sprays, Hirst volumetric spore traps were operated in the areas under investigation for several consecutive years. An estimate was made of the 'relative ascospore dose' (Hirst and Stedman, 1961) for the years 1962-66, by totalling the hourly estimates of ascospore concentrations for each year (Fig. 1). The figures do not represent actual total inoculum in the orchard but they are useful for comparing the inoculum levels between years and within orchards where different treatments are applied.

In the years preceding 1962, disease control was good and as leaf infection was low, the ascospore dose remained low in each of the following springs. In the summer 1962 no scab sprays were applied, the level of foliage infection increased and this resulted in a high ascospore dose in the spring 1963. Foliar infections were allowed to proceed unchecked during the summer 1963. In the autumn 1963 a section of the orchard was sprayed with 0.01% PMC and this treatment was repeated just before bud-burst in the spring 1964. The remaining trees were not sprayed. Assessment of the ascospore dose in the spring 1964 showed that in the untreated section, the spore concentration had risen to 13500 ascospores/m^3 of air whereas in the section receiving the dormant season eradicant treatment, the upward trend was reversed and the ascospore dose fell below the 1963 level.

In the autumn 1964, 5% urea was substituted for the PMC treatment, and the design of the experiment was changed. The previously non-treated area was sprayed with 5% urea and the area which had been treated with PMC was divided into two, one half received 5% urea and the remainder was non-sprayed. Assessment of the ascospore dose in the spring 1965 showed a steep fall in ascospore concentrations in the urea-treated blocks, particularly in the hitherto untreated section. In the area which did not receive the autumn spray the relative ascospore dose resumed its upward trend.

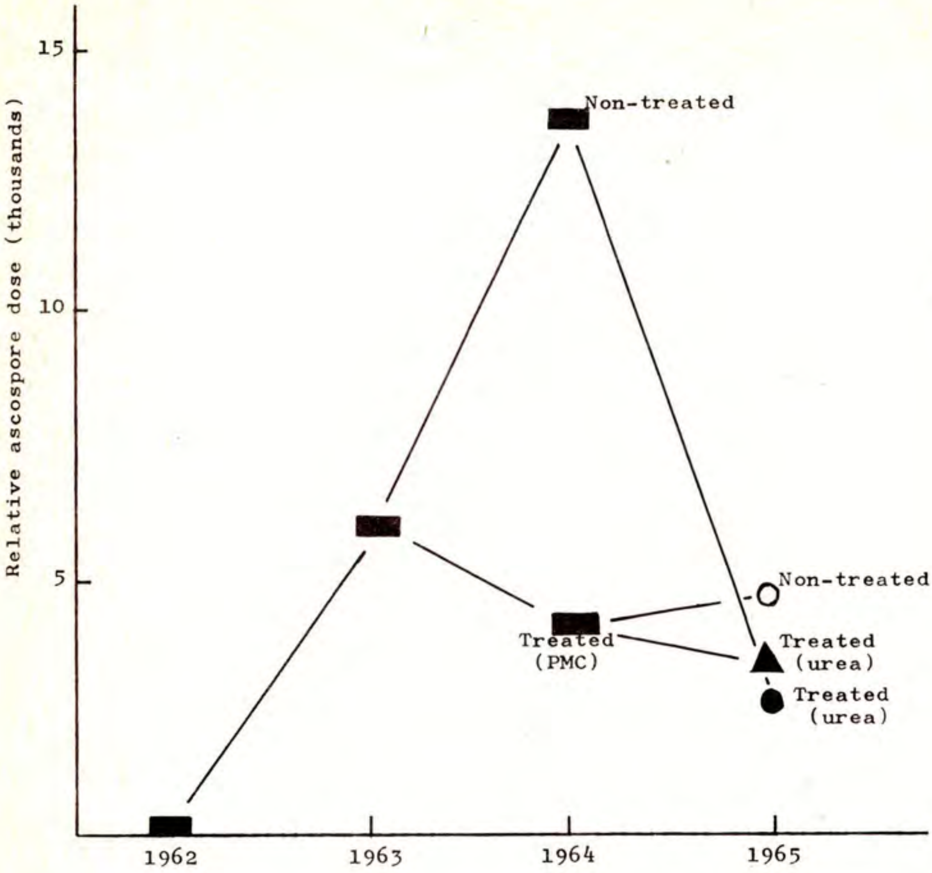

Fig. 1. The effect of PMC and urea treatments on the relative ascospore dose 1964, 1965

The effect of autumn sprays of 5% urea on perithecial development

The value of urea as an alternative to PMC and the mode of action of urea in preventing perithecial development will be discussed elsewhere. Laboratory experiments (Ross, 1961) had shown that a high nitrogen level in media on which opposite strains of *V. inaequalis* were present prevented perithecial development. Later experiments (Burchill, Hutton, Crosse and Garrett, 1965) demonstrated that treatment of scabbed leaves in the autumn with 5% urea prevented perithecial formation. It was assumed that this suppression was due to the high nitrogen content of the urea. However, recent experiments (Ross and Burchill, 1968) have shown that this drop in ascospore numbers following urea treatment is not entirely attributable to the toxic effect of the nitrogen but may be partially explained by the fungicidal action of the urea in eradicating many of the leaf infections in the autumn. Furthermore, the presence of urea on fallen leaves has been shown to favour the development of a microbial population containing bacteria antagonistic to apple scab (Crosse, Garrett and Burchill, 1968).

A final effect of urea which might be regarded as truly eradicant in action is that treated leaves rapidly decompose and are quickly removed by soil organisms; therefore leaves which might have borne perithecia have disappeared by the following spring (Burchill, 1968).

DISCUSSION

In the control of fruit tree fungus diseases emphasis has been mainly on the chemical protection of the host plant and little attention has been given to direct methods of controlling the pathogen by removing the source of infection. The introduction of curative spraying represented an attempt to shift the emphasis towards sprays applied specifically to destroy the germinated spore rather than to protect the plant. However, the source of the inoculum and the influence that its concentration might have on the initiation of a new disease cycle was ignored.

The purpose of the recent work has been to study the improvements in disease control that may be obtained by eradicative measures that virtually eliminate spores. Such an extreme reduction in spore concentrations may be unnecessary, however, and a certain spore level may be tolerated without detriment to disease control. For example, with coffee leaf rust (*Hemileia vastatrix*) the optimum spore density necessary for successful infection lies between 15 and 30 spores/cm^2 of leaf; below 7 spores/cm^2 pustules are rarely produced (Bock, 1962a). Fungicidal treatments that reduce the uredospore concentration below that of the numerical threshold of infection have provided effective control although some spores were present (Bock, 1962b).

The importance of the threshold level of inoculum concentration necessary for the establishment of apple mildew and apple scab infections remains to be investigated but it seems likely that both diseases, particularly the former, can be controlled effectively with a spray programme that does not completely inhibit spore production.

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CONTROL OF BACTERIAL CANKER OF CHERRY BY ERADICANT SPRAYS

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Although bacteria cause relatively few diseases of major economic importance, most of these have proved notoriously difficult to control. Among the more intractable diseases is bacterial canker of stone-fruit trees caused by Pseudomonas morsprunorum, one of the major factors limiting the successful cultivation of cherry in south-east England. Experiments over many years have shown that the severity of the disease can be considerably reduced by Bordeaux mixture sprays applied during the autumn (Moore, Crosse and Bennett, 1959). The sprays are particularly effective on young trees where it is possible to obtain good coverage of the foliage. A study of the mode of action of Bordeaux mixture has left little doubt that the control achieved is mainly due to the destruction of inoculum and not to protective effects of the sprays. Before presenting the evidence for this, first it will be necessary to outline the main features in the epidemiology of the disease.

Annual cycle of bacterial canker

Bacterial canker is a cyclic disease in which a winter canker stage in the stems and branches alternates with a summer leaf spot stage in the foliage (Crosse, 1966). Cankers originate in the autumn through wounds and leaf scars and persist until early the following summer when further progress of the cankers is arrested by defensive reactions in the host and the bacteria in them die out. Leaf infections take place in the spring, through the stomata, while the main crop of leaves on the fruiting spurs is still immature and the cankers still active. Secondary infection of young leaves on the extension shoots may occur successively during the summer, but these usually account for only a small proportion of the total leaf present on the trees at the end of the growing season.

Source of inoculum for canker infections

It was originally believed that the leaf spots were the main source of canker infections (Wormald, 1937) but there is now a good deal of evidence to the contrary. Elimination of the leaf spot by spring sprays of Bordeaux mixture for example did not prevent canker infections in the following autumn (Montgomery and Moore, 1945). Furthermore, it has not so far been possible to demonstrate any relationship between the incidence of leaf spot and the incidence of canker in the same season (Crosse, 1963). Finally, most of the bacteria in leaf spots have been shown to die out during the summer (Crosse and Bennett, 1955). In a search for alternative sources of inoculum it was discovered that large populations of Ps. morsprunorum were present on the leaf surface during the whole of the growing season (Crosse, 1963), and it is now generally accepted that these are the main source of infection for cankers during the autumn.

The pathogen appears on the leaf surfaces soon after bud break and persists there as the dominant component of the epiphytic flora until the last leaves fall in November. It is washed from leaves in rain and is present in large numbers in water draining from stems and branches. The size of the leaf surface population in any given season depends on the age and variety of the trees, but is not related to the numbers of leaf spots or cankers on the trees (Crosse, 1963). It has been concluded from this that the populations are primarily the result of epiphytic growth of the pathogen in dew or in static water left on the leaves after rain. This is strongly supported by the fact that significant concentrations of the pathogen are found in rain water when the trees are in leaf, but at no other time of the year (Shanmuganathan, 1962).

Quantitative aspects of canker infection

The majority of cankers on young cherry trees originate from bacteria sucked into the leaf scars through the broken ends of the leaf trace vessels by the negative tension in the vascular system of the tree. The rate of infection is determined by the numbers of bacteria penetrating into the vessels, and it increases with the inoculum concentration (Crosse, 1957). The relationship between the two factors over the inoculum concentration range 10^2-10^7 bacteria/ml has been shown to be of the dosage response type. From dosage response curves for 6-7-year-old trees of the variety Napoleon, inoculated in the most sensitive period for leaf scar infection (late September-early October), the median threshold concentration of inoculum was estimated to lie between 10^4-10^5 bacteria/ml (Crosse, 1966). Later in the season, when intake of bacteria is restricted by the lower vascular tension in the trees, it is almost certainly higher.

The concentrations of inoculum available for infection of 6-7-year-old trees of Napoleon, determined by plating out rain water from the trees was found to vary during the season from 10^2-10^5 bacteria/ml with seasonal means, in two successive years, of approximately 10^4 bacteria/ml (Shanmuganathan, 1962). It will be seen that this is about the same order as the median threshold concentration during the most sensitive period. Two important conclusions follow from this. Firstly, the inoculum concentration is already a limiting factor in canker infections even before trees are sprayed. The maximum rate of infection in the field, for example, could not be expected to exceed 50% assuming that all bacteria mobilised from leaf surfaces during the sensitive September-October period penetrated into leaf scars. Secondly, comparatively small reductions in the inoculum concentration resulting from sprays should theoretically lead to significant reductions in the incidence of canker infections.

Effect of Bordeaux mixture sprays on inoculum concentration and canker infections

The results of two typical experiments, described in detail elsewhere (Crosse, 1962), are summarised below. The first experiment tested the effects of a single Bordeaux mixture spray (2-3-100) applied in the spring at petal-fall. The spray was found to be highly destructive of the leaf surface bacteria, with the result that the ratio of numbers on the sprayed and unsprayed trees was observed to be less than 1:2000 three days after application. The full effects of the spray did not persist, however, and during the growing season there was a progressive recovery in the leaf surface populations on the sprayed trees, although they never attained the same level as the populations on the controls (Table 1). Between late May and July the ratio of the mean population on the sprayed and unsprayed trees was

1:45. Between July and late September the difference had narrowed to approximately 1:6, and in late September to November the ratio further decreased to 1:5. The depressive effects of the Bordeaux mixture thus persisted until the autumn, and during the crucial period for leaf scar infection there was only one bacterium available for infection on the sprayed trees compared with five on the unsprayed controls. Although this was equivalent to a reduction in the log. inoculum concentration of less than 0.7, it was nevertheless sufficient to reduce the incidence of cankers on the sprayed trees by 57%. This result accorded with the theoretical predictions above.

In the second experiment two sprays were applied in the autumn on 2nd September (2-6-100) and 4th October (6-9-100) respectively. The combined effect of these sprays was to reduce the leaf surface populations during the leaf scar infection period to a 1:18 ratio compared with the unsprayed controls (Table 1). This was equivalent to a reduction in the inoculum concentration on the sprayed trees of approximately log. 1.3. The decrease in canker infections expected from this was estimated from the dosage/response curves to be between 70-90% (assuming mean field concentrations of inoculum on unsprayed trees of log. 4/ml). The actual decrease in cankers recorded the following year was 85%.

Table 1.

Numbers ($x10^6$) of *Ps. morsprunorum* on sprayed and unsprayed trees (per g dry wt of leaf)

Experiment 1

A single Bordeaux mixture spray on 18th May (2-3-100)

	Period after spraying					
	May-July		July-Sept.		Sept.-Nov.	
Treatment	means	ratio b/a	means	ratio b/a	means	ratio b/a
(a) No spray	1.36	1:45	1.42	1:6	3.14	1:5
(b) Bordeaux mixture	0.03		0.24		0.62	

Experiment 2

Two Bordeaux mixture sprays on 2nd September (2-3-100) and 4th October (6-9-100)

Treatment	Before spraying (July-Sept.)		After spraying (Sept.-October)	
	means	ratio b/a	means	ratio b/a
(a) No spray	4.14	1:1	2.75	1:18
(b) Bordeaux mixture	3.90		0.15	

Note: Ratios shown to nearest whole number for simplicity.

Conclusion

Despite the lengthy infection period for cankers on young cherry trees, two Bordeaux mixture sprays applied at an interval of 3-4 weeks during the autumn are usually sufficient to give a level of control approaching 90%. It has been suggested in the past that the effectiveness of Bordeaux mixture is due to its persistence as a protective bactericide. It is difficult to explain the control of leaf scar infections in this way, however. The majority of scars are not exposed at the time sprays are applied. Protection of these would require considerable redistribution of spray material and would only be possible if Bordeaux mixture retained its full bactericidal activity for prolonged periods. Studies of its effects on the leaf surface populations of Ps. morsprunorum have shown very clearly that it does not. After the initial 'kill', increases in the surviving populations were detected within three days while heavy spray deposits were still clearly visible on the trees. It is clear from the relationship existing in the field between inoculum concentration and the rate of leaf scar infection that it is unnecessary to postulate a protective activity for Bordeaux mixture. The whole of the control it gives in the field can be explained by its eradicative effects on the leaf surface inoculum.

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SESSION 5B

DISCUSSION

Mr. P. S. Hamer: What is the point of using autumn applications of Scab control materials if the grower is achieving good Scab control by Spring and Summer sprays:

(a) In the light of Mr. Cartwright's findings, and
(b) In view of the fact that the cost of the Scab spray programme is not necessarily reduced?

What effect is the mercury application for Scab control in the autumn (at relatively low levels of Hg) likely to have on Gloeosporium and is there a chance of an adverse effect following a partial suppression of the Gloeosporium spores?

Dr. R. T. Burchill: Whether or not to apply the dormant season treatment depends to some extent on the level of disease incidence at leaf fall.

If Scab is extremely low or virtually absent, then it would probably be better to omit mercury sprays and rely upon nature in the form of microbial and earthworm activity to remove most of the leaves. If Scab infection is moderate then an application of mercury in the autumn would restrict perithecia development. This application of mercury could be made either in the autumn to prevent perithecia formation, or just before bud burst to prevent the release of ascospores from peritheciae that might have been formed. PMC at 0.01 or at 0.005% would be effective in this context.

If Scab is severe then both on autumn and pre-bud burst spray would be advise-able. In this case the strength of PMC should be 0.01%.

It should be noted, however, that many orchards carry a fairly high level of pin-point lesions on the undersurface of the leaf and these are barely visible to the naked eye. Such infections are responsible for a very high ascospore productivity.

Applications of mercury sprays in the autumn are not expected to present a problem from the angle of increased spore productivity from Gleeosporium spp. wood infections.

Mr. J. H. Bryant: There has been an upsurge in the incidence of apple canker in recent years. From the practical point of view, particularly in a wet autumn, where both Scab and Canker are important, can a grower mix a copper fungicide with the post-harvest mercury spray to attack both diseases or does the presence of Copper antagonise the effect of the mercury on the Scab mycelium?

Dr. R. T. Burchill: The effect of dormant season sprays of PMC on Nectria incidence is under investigation by Miss M. Berrett (East Malling Research Station). Preliminary results indicate that this treatment may be effective in controlling Nectria. However, a larger more detailed trial is now in progress and by 1968 it should be possible to fully evaluate the effectiveness of a mercury-based programme for Nectria control.

With regard to copper sprays and their effect on apple Scab, we have evidence that Bordeaux sprays applied in the autumn (post-harvest pre-leaf fall) stimulate Scab perithecia production. More peritheciae and hence ascospores were obtained from Bordeaux-treated leaves than from non-treated leaves. Other forms of copper-based fungicides have also been found to be stimulatory.

Mr. P. H. Harding: Is the bacterial population on the leaves of a resistant variety of cherry the same as on a susceptible variety? And does the answer to this question affect the way in which we should use resistant varieties? i.e. is the resistance of a resistant variety likely to break down if it is exposed to heavy infection from an adjacent susceptible variety?

Dr. J. E. Crosse: The amount of inoculum on the leaf surface of a susceptible variety like Napoleon is about four times as great as on a resistant variety. In theory, therefore, the susceptible variety might contribute bacteria for the infection of the resistant. But the distance over which the inoculum would need to travel would result in dilution below concentrations of any significance.

Since the resistant variety already requires about 30 times as many bacteria to induce infection compared with a susceptible variety transfer of inoculum from tree to tree is unlikely to affect performance of resistant varieties.

Mr. F. W. Webb: Mr. Cartwright has given us an interesting account of the changeover from 15 applications of organo-mercury sprays in a season to other organic fungicides. Has he observed any changes in the incidence of apple mildew and apple canker and if so, would he attribute this to the change of fungicides?

Mr. J. Cartwright: It is difficult to relate the reduction of mercury sprays to the incidence of Nectria canker, especially fruit storage rots. Increases in the use of nitrogeneous fertilisers with increasing age of the trees is probably a greater factor in increasing the incidence of apple canker.

It could be that the reduced used of mercury is leading to an increase in mildew infection. At present, about 10% of trees are infected and of this about 80% is confined to extension growth infection.

Mr. P. H. Harding: Present day cultural methods with blackcurrants e.g. continuous straw mulch and the use of weedkillers mean that leaves are present on the soil surface throughout the Winter, ready to start leafspot infections in the next season. Would a urea spray before leaf fall aid in the decomposition of the leaves as it has been shown to do with apple leaves for the control of apple scab?

Dr. A. T. K. Corke: Any treatment which leads to removal of the supply of food materials on which fungus depends for the development of spores would be expected to have this effect. Other materials have been tried at Long Ashton with success, but I can say no more about these at present.

Mr. P. Wiggell: In reply to a question by Mr. Marsh, we have not yet tested the application of 10% lime sulphur on the Victoria type of blackcurrant varieties.

10% lime sulphur has only been used to date as a "stump" treatment on cultivar Wellington XXX.

Mr. N. G. Morgan: While we are on the subject of "inoculum suppression", have Mr. Geering and his colleagues considered using materials for control of fruit tree red spider mite, aimed at the winter eggs but applied in the spring? Applications at this time would avoid winter spraying and would possibly be easier than spraying when the tree is in full foliage.

Mr. Q. A. Geering: Tests with NC 5016 pre-blossom to control winter eggs in the spring were not successful.

Mr. T. J. Legowski: Is there any indication with NC 5016 to translaminar or systemic activity? Is the material active against all stages of red spider?

Mr. Q. A. Geering: There is no translaminar or systemic action with NC 5016. The degree of persistence observed is probably due to the active material being dissolved in leaf waxes, as it is highly lipophylic.

Activity is good against mobile stagesof *P. ulmi* and Tetranychid mites. Ovicidal action is good for Tetranychid mites, but uncertain in the case of *P. ulmi*.

We have no information on the effect on mite egg production.

THE SIGNIFICANCE OF PEST AND DISEASE DAMAGE IN THE PRODUCTION AND MARKETING OF PROCESSED VEGETABLES

J.W. Bundy
Birds Eye Foods Ltd.

Summary

The present and future size of the U.K. Quick Frozen Vegetable Industry is discussed and a brief description of the current procedures for obtaining satisfactory raw material is given.

The problems arising in the Industry in handling vegetable raw material which is diseased or contaminated with various pests are described.

The procedures currently used to ensure that raw material supplied to the factories conforms to product specification are outlined and the existing limitations of these procedures are emphasised.

Specific pests and diseases which are particularly troublesome to the processor are mentioned, and a summary of the outstanding problems which need to be resolved is given.

Acknowledgements

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Mr. Chairman, Ladies and Gentlemen -

All of us welcome an opportunity to discuss our problems, particularly with a captive audience, but in presenting this paper I have two major difficulties. The first is the realisation that no one man can speak on behalf of an Industry which is so diverse as Food Processing, involving as it does, canning, dehydration, prepacking and quick freezing. Much of what I have to say probably applies to the Industry in general, but my comments will refer mainly to the quick freezing Industry and it cannot be assumed that they apply to all other vegetable operations.

My second problem lies in the fact that the people here today cover a wide range of interests, including chemical manufacturers, agricultural engineers and advisory people, growers and farmers and other allied interests in the growing and processing Industry. I have therefore decided that my best contribution would be to present a general paper which provides a background to the more technical and specific papers being presented during the morning. Having made these qualifications, I would like to discuss the significance of pest and disease damage in the production and marketing of vegetables for processing.

Let me say immediately that the existence of pest and disease damage in raw material allocated for processing presents major problems to all involved in the Industry. The problem is a technical one in that it creates production difficulties in the factory and the field. It is a marketing problem in that it affects the quality and presentation of the saleable product, and it is a commercial problem in that the technical and marketing issues need to be satisfactorily resolved for the Industry to progress.

To resolve these problems calls for complete co-operation with people such as yourselves, many of whom spend much time and money on development and research to eliminate the particular problems we are considering today. To convince you that the Industry is large enough and the problems important enough to justify your continued interest and investment, I feel it necessary to indicate the size of the market we are discussing, and perhaps more important, the extent to which this market will expand in the foreseeable future.

I also think it necessary to indicate to you the way in which the Industry obtains its raw material so that you can see for yourselves the type of farming operation against which you would apply and operate control procedures which could minimise the problem of pest and disease damage.

I will briefly comment on the procedures we currently use to ensure that raw material supplied to the factories conforms as much as possible to product specification and, in particular, underline the existing limitations of this procedure. I will also try to indicate how the nature of the operation itself is changing the emphasis on the importance of certain pests and diseases and has even created new disease problems in the form of non-acceptable raw material.

Let us then consider some interesting facts about the most important person to us all, namely, the British consumer - and let us look at some vital statistics of the modern housewife. We know she marries at 22, has two children (presumably later) and spends £5.17s.0d., per week on food, that is about 25% of the family weekly wage. We know that she spends 17% of her food budget on fruit and vegetables and we know too that she is spending an increasing amount on convenience foods, in fact, more than £1,200,000,000 in 1966.

The canning Industry is already long established as a convenience food industry in this country, but the frozen food and pre-packing Industries have arrived within the last 20 years and have rapidly expanded in this time. In fact, quick frozen vegetables alone now represent about 11% of all green vegetables eaten in the home, and the market in 1966 reached a total value of £37,000,000 which is about 34% of all frozen food sales in this country. In tonnage terms

SLIDE I shows the U.K. quick frozen vegetable production during 1956-1966. SLIDE 2 shows the same vegetable figures, but includes the frozen fruit tonnage produced over this period. SLIDE 3 shows a breakdown of the main vegetables frozen in the U.K. during the years shown.

You will notice that green peas is the major vegetable quick frozen, but that green beans and, to a lesser extent, brussels sprouts contribute substantially to the overall tonnage. 'Other varieties' include spinach, carrots, cauliflower and potato products.

The next SLIDE 4 shows the significant changes in the pea acreage grown in this country during the period 1956-1966. SHOW SLIDE GIVING BRITISH PEA HARVEST 1956-1966. You will see the increase in the acreage of peas grown for vining, by which I mean quick freezing, canning green and dehydration, and how they have replaced green peas for market and to some extent peas harvested dry.

You will see that the next SLIDE 5, which is shown by permission of the Potato Marketing Board, indicates the same trend in the consumption of potatoes, namely, an eight-fold increase between the period 1955-1970 in potato utilisation for processing at the expense of ware potato usage. In other words, about 20% of the total potato consumption in this country will be in prepared form which, incidentally, is still a long way from the American pattern where, by 1970, they expect to be using 50% of their crop for manufacture.

You will see, too, in the next SLIDE 6, which is being shown by permission of the Wye College Marketing Dept., how consumer usage is changing from market to prepared type of vegetable in catering establishments. In general, hotels and restaurants are now buying about half of their products in prepared form.

It is, of course, difficult to predict how the housewife will buy her food 20 years hence, but we can certainly try. By 1987, half of all Britain's food is likely to be in prepared or convenience form compared with 20% today. The consumer is not going to change overnight from one type of food to something quite different. In fact, our food today consists basically of the same ingredients that it did 30 years ago, but what the housewife of the future will be able to do is to try the same thing in a rather different form. Food habits change very slowly, but the rapid changes will be in the way the housewife buys and prepares her food, and there is no doubt that the present trend I have tried to indicate on these slides will accelerate.

We should now consider the ways in which the processing Industry obtains its raw material to meet present demand, and more important, how it will meet the ever increasing requirement that we have discussed. Basically the raw material is contracted with farmers in the local vicinity of the processing factories for obvious quality and cost reasons. It is, of course, no coincidence that the factories are sited mainly in the eastern arable regions of the country, and in particular on the sea coasts, in order to obtain adequate fish supplies.

Within the last 10 years, the vegetable acreage contracted in the locality of these factories has dramatically increased, and traditional hand-harvesting methods have rapidly given way to mechanical harvest and bulk transport systems, which can allow high volume throughput and quick despatch from field to factory, to maintain optimum quality in the produce. The following slides give an indication of the way in which the raw material is mechanically harvested and illustrates the large unit size of farm operation which must now be handled, mainly through an increasing use of machine and farm labour syndicates.

SLIDE 7 - Showing Spinach Harvesting.
SLIDE 8 - Showing Pea Harvesting.
SLIDE 9 - Showing Green Bean Harvesting.
SLIDE 10 - Showing Sprout Harvesting.

It is therefore not unusual to have from 15-20,000 acres of vegetables contracted within a 20 mile radius of a single factory, and when one considers that the major part of the processing industry is centred in the eastern counties, the effect on the farming scene becomes most marked and one begins to see the implications of such intensive vegetable production in a restricted area.

Processors contract their vegetables on the basis of strict rotational practise to minimise the risk of build-up of disease in these crops. However, it may be that such intensive vegetable production is increasing the build-up of specific pests and diseases, such as aphis on peas, cabbage root fly on brussels sprouts and soil borne diseases such as fusarium foot rot and eel worm.

SLIDE II - Fusarium Foot Rot in Green Beans.
SLIDE 12 - Aphis on Sprouts.

Seed borne diseases may also increase in these areas, if strict attention is not paid to the continued use of healthy seed, and I would mention such examples as phoma disease in brussels sprouts, and halo blight in green beans.

SLIDE 13 - Phoma on sprouts.
SLIDE 14 - Halo Blight on Beans.

The change in the harvesting system from hand picking to mechanisation has in itself certain implications, in that certain crops are now virtually disappearing, such as runner beans and with it the problem of bean rust, although it has been replaced by the far more serious problem of botrytis in dwarf beans.

The non-discrimination of harvesting machines has emphasised the changes in the relative importance of diseases. We now find that diseases which generally occurred in low incidence and were not considered economically important when the crops were hand picked, since the affected produce was left on the field, are now extremely important because their presence in factory intakes, even to a small extent, has a serious effect on factory throughput cost. Another example, is the presence in green beans of botrytis rot, which occurs annually to varying extents. This needs only to build up to 5% or 6% in the crop received at the factory to present a major problem in production.

Even at 3% level 25% of the inspection belt labour is occupied solely in removing botrytis infected beans. The presence of such diseases in a crop is not helped by the fact that bulk transport and handling is on the increase, and disease spread in boxes and in bulk can be rapid in a matter of hours.

Now I should say a few words about the pest and disease control procedures we use and their present limitations. In general the major processing companies employ specialist fieldstaff to control the raw material operation at all stages. In our case, fieldstaff are kept up-to-date with the ever increasing number of chemicals available, by means of his Fieldman's Handbook, which lists amongst other things, all brand chemicals, their active ingredients and the Company's recommendations on their use.

Recommendations for use depend not only on the efficiency of control on any particular pest or disease, but whether it is likely to affect the quality or flavour of the raw material before or after processing. Use of a product also has to conform with existing Chemical Approval Schemes and Manufacturers' recommendations. It should be emphasised that whilst the processor may stipulate restrictions on certain chemicals, his control on farmer choice of chemicals is limited to a recommended list with the final decisions being taken by the grower.

Records of all crops are kept by the fieldstaff and presence or absence of particular pests and diseases are recorded. These are computerised to build up an annual picture of the importance and prevalence of different pests and diseases within and between different years and different areas.

Fieldstaff spend all their time during the growing season supervising the development of contracted crops and are therefore on hand to make the necessary recommendations to farmers if any outbreak of pest or disease is seen to occur. This, however, gets increasingly difficult when the harvesting season commences and when time is at a premium with the fieldsman. It is here perhaps that some system of forecasting, such as that for potato blight or pea moth, can be extended to the more major and common vegetable pests, to allow a satisfactory precautionary spray programme to be applied.

Processors normally supply growers with seed and seed borne diseases are kept to a minimum by strict regard to phytosanitary requirements with the seed suppliers. Guarantee of absolute freedom of seed borne disease in a shipment of seed can rarely be given since any practical field check and seed testing procedure have their limitations, particularly when the numbers of seed which are probably infected are so infinitely small. Nevertheless, research work is currently being carried out to determine more definite sampling procedures for indentifying seed borne disease incidence.

Control through legislation by the provision of phytosanitary certificates is, therefore, unlikely to guarantee elimination of seed borne problems. The best safeguard is through an intimate knowledge of the supplier, the area and conditions where the seed is produced and the hygiene procedures by which he makes his seed.

In considering the need to control pests and diseases in raw material for processing, it it important to recall that we are dealing with produce which will ultimately be made available to the consumer under a brand name. The consumer is well aware that her own garden and market-bought produce can, and frequently does, contain aphis, caterpillars and slugs etc., and these she removes during preparation in the kitchen. She would be fairly upset if she found one at the dinner table and more so, if a guest found it. Any pre-packaged food is expected to be completely clear not only of animals, but also of any trace of their depredations on the crop. This gives the manufacturer or packer a very large problem. There are numerous systems used to help remove these pests at the factory, but here we are concerned with preventing them being present in the crop.

For a branded product, every consumer complaint is of great concern to the processor. Indeed it is an offence against the Food Hygiene Regulations. We would consider one complaint of, say, a slug or caterpillar, in every 10,000 packets as being a seriously high level, but if only one in ten of the consumers were complaining, the content would in fact be, one in every 1,000 packets. In terms of crop infestation, this would mean five slugs or caterpillars per acre, or if we are removing 99% in the factory, 500 slugs or 500 caterpillars per acre. One can, therefore, imagine the tremendous shortcomings of any control procedure which eliminates say 65 - 70% of the pest or damage. This is nothing like the level of control required to make any impression on the processors problem.

It is, therefore, evident that the levels of field control to which we have been accustomed can no longer be tenable for processed crops. It is no longer sufficient to control a pest in the field to a level where crop yields are no longer reduced, we must meet a level of control which allows the processor to handle large quantities of raw material on a mechanical field and factory scale, to ensure that his product is completely acceptable to the consumer on both quality and cost terms.

Therefore, it is likely that as chemical manufacturers produce the chemicals which increasingly meet the specification of pest and disease elimination in the field, the decision on which chemical to use will pass from the grower to the processor. This is inevitable because it is the processor and not the grower who can distinguish at this level which pest or disease poses the greatest cost or problem to him during factory production, and who can best emphasise the choice of control measure which eliminates the production problem as well as the field problem. Another reason why the decision on choice of control measure may pass more to the processor lies in the fact that many current factory production problems arise from crop disorders which present little economic problem to the farmer.

Internal infestation of sprouts with cabbage root fly larvae, see SLIDE 15, and botrytis rot on green beans are two such disorders which present far more serious problems to the processor than to the grower when occurring at low level incidence.

Disorders such as Internal browning of sprouts - see SLIDE 16 - the cause of which is not fully known and Evesham stain in broad beans, as shown on the next SLIDE 17 and which is caused by virus infection, cannot be controlled. Neither of these disorders are likely to contribute to field yield losses, but they are both seriously limiting factors in processing as their presence even to a small extent, can stop a production line.

The only way of controlling such problems at the present time is in crop rejection which is no satisfactory answer to the farmer or processor.

The cost of controlling pests and diseases in the field, needs to be kept to a minimum, but the value of an efficient spraying material and its application must not be seen only from the grower's eyes. The excessive cost to the processor of handling infested or infected crops must be considered when assessing the relationship between control efficiency and control cost in the field. The fact that the grower currently carries all costs of spray material and application should not necessarily be over-emphasised since this can always change in the light of different circumstances.

Research is currently being done by our own Company on such serious problems as internal browning of sprouts and this is being continued. Similarly, control measures to prevent the spread of disease in bulk transport such as occurs in botrytis in green beans needs to be studied. We need pesticides which are persistent and effective in wet weather or in continued dry conditions where the existing systemic insecticides are not effective. We need persistent fungicides which can control or prevent the spread of foliar diseases such as botrytis in beans and downy mildew in peas, and we need new mechanical systems for applying the chemicals if they are available. Perhaps we will see the hovercraft spraying machine doing this some day. We need more effective seed dressings to overcome the seed borne diseases and we need more information on the host range of specific soil borne diseases. We need all these chemicals which are efficient biologically, but which also do not produce off-flavour or taint on the product and which will conform to any future legislation regarding residue tolerance level on the crop.

We need to improve our communications in every facet of the Industry. If the problems which are confronting the processor today, are the problems which will involve the bulk of the vegetable industry 10 years hence, and I have tried to indicate that this is the direction in which it will go, then it is important that these problems be communicated at the earliest possible time to the various Government and Private research stations which are set up to do this work. This is already extensive in such research centres as Chipping Campden and N.V.R.S., Wellesbourne.

The chemical manufacturer and agricultural engineer must also appreciate that these problems are of an extent which warrants their increasing investment and effort, and I hope that I have shown this to be so. It is also important that the chemical manufacturer communicates his information on the use and availability of chemicals, not only to growers, but to processors as well, who in the end must determine the use of these sprays on contracted crops.

Finally, the problems concerning all of us in this sphere must be adequately communicated to the various Government Departments which set up the legislation on use of chemical sprays on edible crops, so that they can better judge the effect of future legislation on a rapidly expanding Industry.

SLIDE 2

U.K. PRODUCTION OF QUICK-FROZEN FRUIT AND VEGETABLES 1956-1966.

	VEGETABLES TONS	FRUIT TONS
1956	23,936	1,215
1957	30,054	1,029
1958	31,568	1,455
1959	41,991	1,022
1960	57,600	900
1961	68,000	1,200
1962	79,800	1,300
1963	79,700	1,200
1964	85,800	1,000
1965	79,700	1,000
1966	97,600	1,300

Source: Ministry of Agriculture, Fisheries and Food.

SLIDE 3

PRODUCTION BY VARIETIES

	1964	1965	1966
	TONS.	TONS.	TONS.
Green Peas	54,900	50,500	61,000
Green Beans	13,900	12,500	17,200
Brussels Sprouts	6,200	3,900	5,000
Broad Beans	1,700	1,900	1,400
Other varieties	9,100	10,900	13,000
Totals	85,800	79,700	97,600

SLIDE 4

BRITISH PEA HARVEST 1956-1966 — Thousands of Acres

	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
Peas, green, for quick-freezing)						(36.3	38.2	45.7	48.3	42.5)	
)	51.5	55.9	59.2	66.6	73.6	(				)	87.5
Peas, green, for canning)						(35.8	31.7	37.1	38.3	33.2)	
										)	
Peas, green, for dehydration										7.4)	
Peas, green, for market	36.7	31.1	34.7	29.2	33.1	27.7	30.3	25.6	20.6	18.4	15.5
Peas, harvested dry	104.9	78.1	72.5	55.4	46.7	26.3	22.6	33.8	32.0	34.0	35.2

543 Source:- Ministry of Agriculture, Fisheries and Food and Birds Eye.

SLIDE 6

Expenditure on Fresh and Processed Fruit and Vegetables by Individually Run Catering Establishments

	Overall	Hotels	Restaur.	Canteens	Schools (Private)	Hospitals
Number	(131)	(48)	(37)	(32)	(8)	(6)
	%	%	%	%	%	%
Fresh	52	49.0	58.5	59	33.7	64.5
Frozen	23	33.0	25.5	10	12.4	9.5
Tinned	21	12.5	13.0	27	41.5	23.0
Dried	4	5.5	3.0	4	12.4	3.0

SESSION 5C

DISCUSSION

Mr. G. A. Filani: What are the effects of seed-soaking in thiram on Fusarium sp. and Pythium sp?

Mr. R. B. Maude: This is still being investigated. The thiram deposit on the seed in circulated treatment gives some protection against soilborn fungi. It is also possible that internal thiram may have some effect against such fungi.

Mr. G. A. Filani: Have you made a comparison between seed-soaking and dry seed dressing as methods of control?

Mr. R. B. Maude: Yes. Seed-soaking will cure many internal pathogens whereas dry seed dressing has little effect on them.

Dr. F. H. Feekes: Will there be no deleterious effect on big seeds, e.g. peas and beans by soaking?

Mr. R. B. Maude: Large seeds are not very suitable for treatment by thiram soaking, not only because they are very bulky, but also because, as the questioner states, there are some problems in drying them back. Further research may, however, give information on more suitable drying methods. I should emphasize that we are doubtful whether thiram soaking will be practical for large seeds, but it is very satisfactory indeed for small ones.

Dr. F. H. Feekes: Is it possible to disinfect seeds a long time before drilling?

Mr. R. B. Maude: Tests on this are still in progress, but we know that celery seed can be stored for at least one year after treatment without any deleterious effect.

Dr. F. H. Feekes: Would a soluble product, e.g. nabam, not be more suitable?

Mr. R. B. Maude: We have tested and are still testing many compounds other than thiram. In our tests so far, however, nabam has proved to be too phytotoxic to use.

Mr. C. L. Dunn: Is thiram soak likely to be commercially acceptable on cereal seed?

Mr. R. B. Maude: Although thiram soaking is very efficacious on cereal it seems probable that the bulk of seed involved will rule out the treatment except for nucleus stocks.

Mr. M. J. Zwijns: Have you investigated the differences between seeds in their drying requirement?

Mr. R. B. Maude: Vegetable seeds do differ in this respect. Celery and brassicae are quickly dried and peas take a longer time. We use high air volumes and low temperatures.

Mr. C. G. Parker: Has thiram soak treatment any bad effects on flower seeds?

Mr. R. B. Maude: It may have, as flower seeds are susceptible to thiram damage, and we advise that pilot tests should always be made before treating larger quantities.

Dr. F. H. Feekes: It is essential that when planting out young lettuce plants, roots do not come into contact with thiram dust.

Mr. C. L. J. Ryan: I would agree that thiram can be toxic to root tissue, but in our experiments the roots were not in contact with the chemical.

Miss J. Raisen: Now that dichlofluamid and thiram are on the market is there any scope for any more fungicides against *B. cinerea* on lettuce, or are these existing ones effective enough if used efficiently?

Mr. C. L. J. Ryan: I feel that these fungicides are so good that it is unlikely that better ones will be produced very easily. It is important, however, to pay proper attention to methods of application to obtain maximum effect.

Mr. R. Howes: I notice that you vary the volume of application by varying the pressure. This also varies the droplet spectrum. Has this factor been investigated?

Mr. T. H. Coaker: No!

Mr. B. H. Bagnall: If cauliflower seedlings have to be held in frames for longer periods than normal, due to adverse weather, is there likely to be a serious reduction in the resulting level of disease control?

Mr. C. M. Griffin: I think that this is unlikely, and in fact the plants in our experiments were held for longer than would be normal under commercial conditions.

Mr. D. C. Graham: Has *Pseudomonas syringae* been isolated by you from bean seeds?

Mr. J. D. Taylor: No. Although we frequently isolated other species of *Pseudomonas*.

Mr. D. C. Graham: Are the rough forms auto-aglutinable?

Mr. J. D. Taylor: No, not in normal saline.