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RECENT DEVELOPMENTS IN THE CONTROL OF ECTOPARASITES OF ANIMALS

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Summary Recent developments in the control of sheep blowfly, ox warble, cattle tick and the sheep scab mite are discussed in relation to the appearance of insecticide resistance. Early hopes that biological methods might quickly control ectoparasites such as the screw-worm, have now been challenged. Despite difficulties in some countries with final eradication of arthropod populations, as with warble and scab, insecticides appear at present to offer the only rational means for the control of ectoparasites of animals.

INTRODUCTION

Chemical techniques have always offered and I believe always will offer much the quickest, most effective and most economical means of controlling external parasites of animals - whether they cause damage or transmit a disease. The operative word must remain as "control", because it is very unusual to eradicate completely insect, tick or mite pests of veterinary or medical importance.

After the remarkable surge in new insecticide development during the 1940's and 1950's, we had available organo-chlorine, organo-phosphorus and carbamate compounds, plus the older arsenates, nicotine, sulphur, derris, tar acids, etc. The way in which new developments have taken and are taking place can best be seen by referring to some of the more serious ectoparasites which affect animals in this country and abroad. Some useful reviews of the subject have already appeared (Wood, 1966, 1967a, 1967b; Beesley, 1973), and it is my purpose to discuss only some of the most significant recent advances - and related problems. We can select as examples the control of sheep blowflies (maggot flies), warble flies (cattle grubs), certain ticks of sheep and cattle, and sheep scab mites.

SHEEP BLOWFLY

Lucilia sericata, one of the green bottle flies, is one of the most important ecto-parasites of livestock in Britain. *L.sericata* is also an important pest in New Zealand, although the copper blowfly, *L.cuprina*, replaces it in Australia and South Africa. Blowfly maggots attack the skin of sheep and rapidly cause serious wounds. DDT and BHC were available to farmers in sheep dips in the mid-1940's, and gave protection against fly maggot for several weeks after application, but protection for an entire season was not yet possible. Soon, however, the twin development of dieldrin and aldrin revolutionized sheep husbandry in all countries where strike flies had previously been a menace. Dieldrin quickly proved its superiority and gave protection for a complete season: some farmers even managed to miss an occasional year's dipping against blowfly. A valuable feature here was that the insecticide passes down the fibres and reaches the depths of the skin, and also travels laterally to some extent in the tissue: these "translocations" were especially important to farmers in countries which used low-volume tip-spraying techniques, as in Australia.

There has to be a snag in such an amazingly effective insecticide, and in fact there were two problems. First dieldrin persisted too long as a very stable and non-biodegredable compound in the body tissues, especially fat. Many thought that this gave rise to a public health hazard despite no deaths ever being recorded from the proper use of dieldrin by thousands of people over many years. Dieldrin was therefore "banned" or "voluntarily withdrawn" from use on food animals in just those countries where it had given such good service against a large number of ectoparasites. The second feature, related to the first, was that the eventual tiny residues left in the wool of the sheep long after dipping presented just the right conditions of selection pressure for the development of insecticide resistance, and 50-300 times normal tolerance was recorded in Australia and South Africa where dieldrin had been used against L.cuprina.

Cases of dieldrin-resistance also occurred in L.sericata populations in New Zealand and South Africa (Brown, 1961), with a single report from the Irish Republic (Shaw et.al., 1968). The much-publicised change from dieldrin to mainly organo-phosphorus compounds took place by about 1964 (Leech and Macrae, 1970), but in Australia resistance against these insecticides also was soon reported (Shanahan, 1966; Harrison, 1969). Generally, however, resistance by blowfly to the organo-phosphorus insecticides has not yet had the serious effect on control measures so unfortunately experienced in cattle tick control (see later).

Of the ten or so organo-phosphorus insecticides now in use in Britain for fly maggot control, several are very persistent and at 0.04-0.05% approximately equal dieldrin in performance (e.g. chlorfenvinphos, phosalone, diazinon, and dichlofenthion) while others, such as coumaphos and dioxathion, are slightly less persistent (Wood, 1967a). A few other types of insecticides have shown good effect, e.g. the carbamate butacarb (Harrison, 1969) and certain organo-tin compounds (Hall and Ludwig, 1972), but cross-resistance may eventually arise between the organo-phosphorus and carbamate insecticides, and some of the tins are toxicologically suspect.

In this country dipping is the principal way of applying insecticide to sheep, although some run-through spray races are also used. These give a very rapid application rate of 40-60 sheep per minute and are particularly useful with those organo-phosphorus compounds which have the property of moving down the wool fibres (Wood, 1967b).

By contrast it is interesting that Australia has reported a new lease of life for an unusual type of biological control, the Mules operation: this consists of a surgical correction of the crinkly skin folds characteristic of the breech of Merino ewes, so that this part of the body then retains very little fly-attractive faeces and urine (Richardson, 1971; Bell, 1972). The operation, first used over 30 years ago, has a vogue each time there is a suggestion of impending insecticide resistance in L.cuprina and it is a worthwhile practical means of slowing down the otherwise rapid rate at which insecticides can be used up against succeeding resistant generations of blowflies.

In warmer countries there are many other species of blowflies, such as the "screw-worms", whose maggots attack stock and we cannot leave the subject without mentioning the progress of screw-worm control in the United States. This fly, Callitroga hominivorax, was once controlled by the use of arsenic, then DDT and BHC, and finally the organo-phosphorus compounds were used. At about the same time it was decided to attempt a new form of biological control, in which millions of specially-bred flies were irradiated in order to render them sterile, and then released by air over the countryside. The work progressed from successful eradication campaigns in Curaçao and Florida to a massive scheme which embraced the entire southern United States, plus a wide "buffer zone" on the U.S.-Mexican border. On each occasion, provided an overwhelming population of sterile flies was steadily maintained, the natural fly population of the area declined to zero.

For a few years all went to plan: the total annual number of cases of animal screw-worm infestations declined from over 100,000 to less than 500, but then there was a sharp rise to over 92,000 during 1972 (Anon., 1973). Because of the high fecundity of screw-worm, a considerable effort will now be needed to eradicate screw-worm from the southern United States (mainly Texas), and in the next 5 years the U.S.A. and Mexico have jointly pledged some $40 million for this work. Meanwhile the organo-phosphorus insecticides will undoubtedly play a part in helping to reduce the numbers of this serious pest.

WARBLE FLIES

Cattle grubs begin life as eggs attached to hairs on the undersides of cattle, and their maggots penetrate the skin to start a long migration which takes them either to the wall of the gullet (Hypoderma lineatum) or into the spine (H.bovis). After many months the larvae leave these places and move to the back, where they now penetrate the skin for a second time, but outwards, making a breathing-hole before settling down for several weeks in pus-filled cysts. They eventually fall out to continue their lives as pupae and then as adult flies.

It is extremely difficult to estimate economic losses due to ectoparasites, but figures of £2-3 million for warble loss have been quoted for Britain and France, while in only two Canadian provinces it was over £½ million in 1968 (Rich, 1965). The incidence of warbles in the back reaches a peak in this country during the months of April, May, June and July, as shown in data from the Hides and Allied Trades Improvement Society, and the highest levels of infestation occur in the younger animals, the "ox and heifer" group, where an incidence of 23.9% was recorded in May, 1969 (Figure 1). If the monthly average of "all hides", i.e. "ox and heifer", "cows" and "bulls", is taken this is obviously a much lower figure: 19.1% in May, 1969. As will be seen in Figure 2, the annual incidence for "all hides" fell during the 1960's from over 30% to 8.2% in 1969, after which it rose to 12.2% in 1970, 13.8% in 1971 and 13.5% in 1972. Statistically speaking, there is no difference between the data for 1971 and 1972, the main point being that the incidence of warbled hides has definitely risen since 1969.

Within Britain the annual incidence of warbles seen at sample checks of cattle at livestock auction markets ranges from about 5% in Scotland to 45-55% in the West Midlands and South West (Meat and Livestock Commission, unpublished). The South West seems particularly at risk, and the average monthly warble incidence there is usually well over twice that for the remainder of the country, e.g. in April 1972 73.3% as against 28.3%. Because of these high figures no one would suggest that a national warble campaign would be easy or cheap, but - with the increasing costs of importing clean hides - the potential benefits would be great.

As regards control, maggots which have already holed the skin can be killed by dressing the animal's back with a suspension of the contact insecticide derris, and in 1928 this was made legally compulsory in Britain. The regulation was later revoked, and a free-for-all state now exists in which farmers may (i) scrub on derris to kill mature warbles in the Spring, (ii) kill immature maggots in the autumn before they can reach the back, using suitable systemically active organo-phosphorus insecticides (which can of course also be employed in the spring to contact-kill mature maggots) or (iii) they may choose to do nothing about the disease.

Fig. 1.

Monthly percentages of warbled hides seen at 40 abattoirs in England and Wales, 1961 and 1969 (H.A.T.I.S. data)

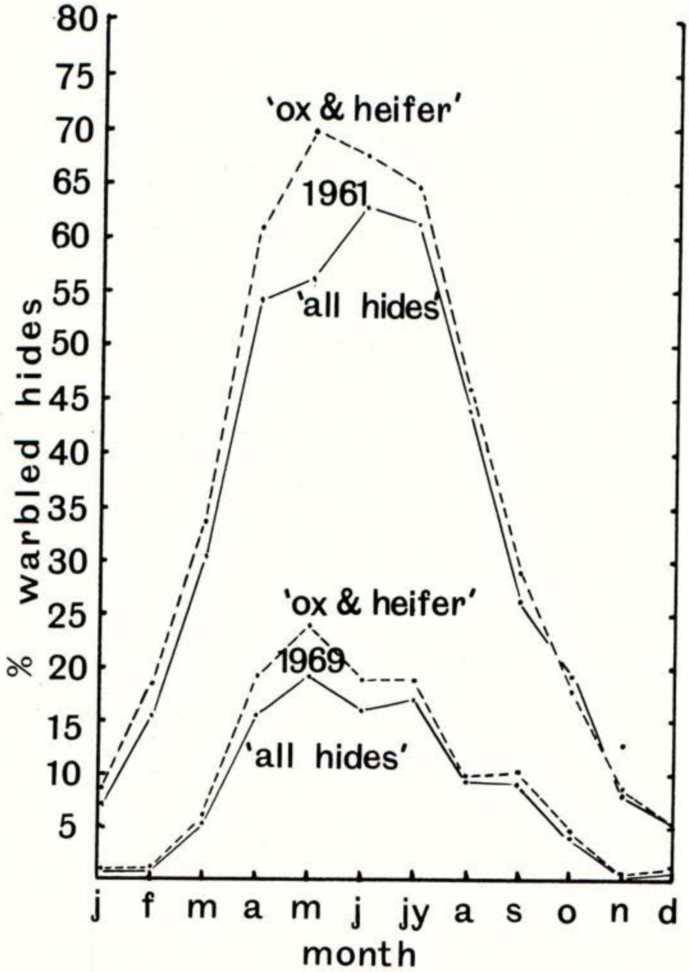


Fig. 2.

Annual percentages of warbled hides seen at 40 abattoirs in England and Wales, 1966-72 (H.A.T.I.S. data)

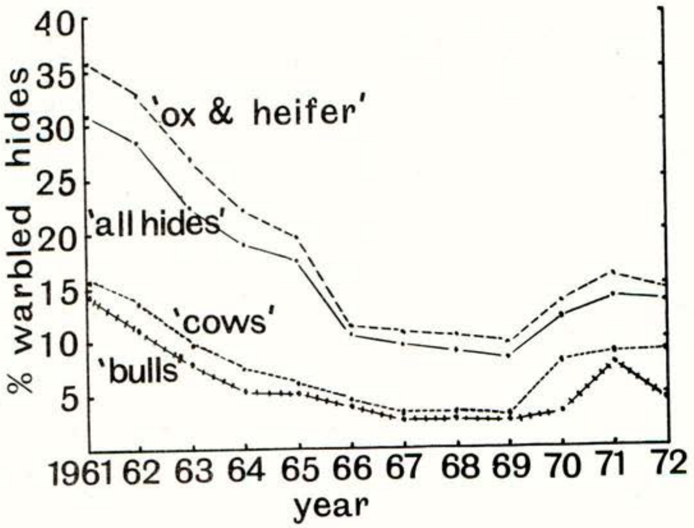
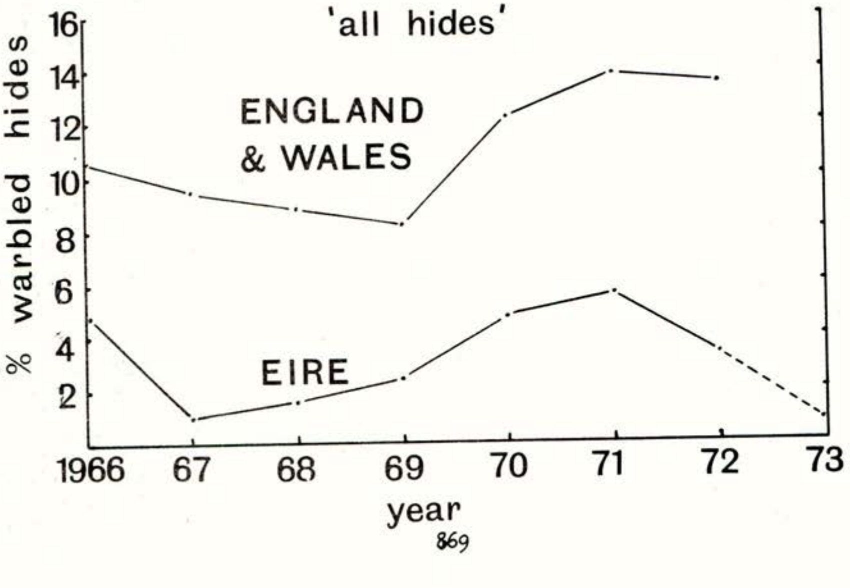


Fig. 3.

Annual percentages of warbled hides seen in abattoirs in England & Wales and Eire, 1966-72 (from H.A.T.I.S. and H. Thornberry)



The organo-phosphorus pour-on insecticides crufomate ("Ruelene") and fenthion ("Tiguvon") are in common use in Britain as prophylactics against warble damage. Such systemics give 97-100% control, and in a recent trial in Nebraska, U.S.A., calves which had been treated once with O.P. insecticides each gained during the following 100 days 12 lb. more than did similar, but untreated, calves (Campbell et.al., 1973).

So can warble be eradicated from this country? Warbles have been completely cleared from Denmark, Sweden, Norway, Cyprus and the Isle of Man, and extremely good control - without complete eradication - has been achieved in several other countries or provinces (Beesley, 1973). The most massive recent campaign is the one mounted in the Irish Republic, where well over 20 million doses of systemic insecticide have been used during the last few years, resulting in around 99.5% control as judged by 1973 data just to hand (Thornberry, personal communication): Figure 3. After the Irish programme, the next most promising campaign is perhaps that in Switzerland, where 130,000-210,000 cattle have been treated with systemics in each of the last three years. The Swiss warble incidence has now fallen to the extent that 15 cantons are now clear, while the disease is uncommon in most of the remainder. This is a very fine achievement in view of the proximity of warbled cattle in neighbouring countries, a problem we do not have to worry us in Britain. Another scheme is in progress in Alberta, Canada, where 2.5 million cattle were treated with systemics in 1972 (Khan, personal communication). In France, Magat (1972) has reported good progress in the eradication of warble from Britanny. Britain, regrettably, has lagged behind other countries, and has set up occasional trials, but nothing that could remotely be described as a national plan for warble control. This seems unfortunate at a time when clean hides are at a premium, and other countries have been able to carry through exceedingly economic schemes which have aroused very favourable comment among hide importers in the E.E.C. One bonus feature in this matter is that we do now have at our disposal the planning experience of the Eireann Department of Agriculture in warble control, experience which has already been used by the Ministry of Agriculture in Northern Ireland to cut back their own warble figures drastically.

On a number of occasions, near-eradication has been obtained, but 100% control has evaded the particular scheme, as in a local programme in British Columbia, Canada (Rich, 1965), when infestation in untreated "bait" animals fell during five years from 30.2 to only 0.2 grubs per animal, only to rise in the next two years to 1.7 and then to 10.2. It has to be concluded that, as with many other insect total control measures, decimation and final eradication are two distinct matters.

CATTLE TICKS

Ticks can develop resistance to many types of acaricides and since Australian and South African Boophilus microplus and B.decoloratus became resistant to arsenic in 1937-38, resistance has occurred to DDT, BHC, toxaphene, carbaryl and most of the organo-phosphorus acaricides. Unfortunately, acute acaricide resistance has been reported in ticks from intensive beef areas of Australia and South America, and a point has been reached in some parts of the world at which high level tick control is no longer possible (Shaw, 1971).

In Australia the first important strain of acaricide-resistant B.microplus was found at Ridgelands (Rockhampton). After 4 years' exposure, Ridgelands ticks had become resistant to dioxathion in 1963, and then showed cross-resistance to carbophenothion, diazinon and to the carbamate carbaryl, but remained susceptible to Dursban (chlorpyrifos), bromophos ethyl, crotoxyphos, coumaphos and ethion, which were therefore available for control. In 1966 the Biarra strain (Brisbane Valley) was detected: it could not be controlled by ethion, crotoxyphos, or coumaphos (Roulston and Wharton, 1967), although Dursban (chlorpyrifos) and bromophos ethyl were satisfactory (Wharton, 1967). Prolate (phosmet) also gave good control against both the Biarra and Ridgelands ticks, but this acaricide tends to lack sufficient stability in the dip bath to stand as a real alternative to the other organo-phosphorus compounds.

The Biarra resistant strain of B.microplus exhibits a difference in its cholinesterase system from normal strains, being less sensitive to inhibition by organo-phosphorus acaricides. This suggests that the best acaricide for the immediate future will not be a cholinesterase inhibitor, and one such compound has been discovered, the formamidine chlorphenamidine, which is closely related to one of the babesicides. Like phosmet, this compound at first seemed insufficiently stable in the dip tank to be of much value, but recent work has shown that the addition of 0.01% chlorphenamidine to 0.025-0.075% organo-phosphorus (or 0.2% arsenic) acaricides gives very good results (Roulston et.al., 1971).

Further strains of ticks resistant to organo-phosphorus acaricides, were discovered in 1968 at Mackay, in 1970 near Mount Alford, and in 1971 at Gracemere (O'Sullivan and Green, 1971).

The resistance problem is most severe and widespread in Boophilus, but also exists in other genera. Fortunately none of these are resistant to the organo-phosphorus or carbamate insecticides, but it is reasonable to suppose that such resistance will eventually develop. If, for example, acute OP resistance were to appear in Rhipicephalus appendiculatus (the carrier of East Coast Fever in Africa) this dangerous disease would become most difficult to control, and cattle farming could become impossible in many parts of Africa.

In South Africa, it has been shown that mixtures of dioxathion and chlorfenvinphos are very effective against cattle ticks (Baker et.al., 1969), and in some tests a 0.025/0.025% mixture gave better results than either constituent at 0.05%. However, the degree of potentiation attained was not sufficient to control the Australian Biarra strain under practical field conditions.

Reasons for the appearance of insecticide resistance in cattle ticks include the ineffective treatment of the animals, leaving too long an interval between treatments, or using weak wash in the dip or sprayer (Shaw, 1971) and conditions on the suspect farm must be thoroughly checked before making any assumption that resistance is actually present; the alternative is to make a premature and undesirable switch to another insecticide.

SHEEP SCAB

Mange conditions are caused by tiny mites, and the most serious to attack sheep is Psoroptes communis ovis, the scab mite, which produces severe skin damage and sometimes death in infected animals. Until the mid-1940's the available scab dips included either arsenic or tar acids. These had only moderate persistence, and a minimum of two dippings were required under the Sheep Scab Orders in this country. During the late war benzene hexachloride (BHC) appeared as a first class acaricide, capable of eliminating scab with a single dipping, and the legal requirements were amended to include the single- and double-dipping type dips. The last outbreak of sheep scab in the United Kingdom occurred in February, 1952, and since that time interest in the disease has waned, and local authorities have allowed their dipping powers to lapse - although the Scab Orders have not been revoked. Several cases of sheep scab continue to appear each year in Eire, and overseas a great many countries have heavily infested sheep. Thus, work on suitable scab dips has proceeded modestly, and some of the organo-phosphorus insecticides have been found effective against Psoroptes, e.g. 0.01% diazinon (Wood, 1967a). By the end of 1971, 57 dips remained officially approved by the Ministry of Agriculture for scab control: 42 containing

BHC and the remainder tar acid, 1970 having seen the last of the arsenic scab dips in Britain.

This was the situation until last winter, when scab once more appeared after a break of twenty years. A total of 27 infected flocks were reported, mainly from the Trough of Bowland area of the western edge of the Pennines. Stringent dipping measures were carried out, and this prevented the spread of scab into the Yorkshire Dales, Peak District, Borders and Wales. The area was declared clean by January 25th 1973, following checks on some 85,000 sheep. It was appreciated that a further outbreak was possible this autumn, and 11 weeks ago two outbreaks were reported from Derbyshire, at Hartington and Alsop-en-le-Dale; these were followed by three further outbreaks in Derbyshire, two in Flintshire and one each in Staffordshire, Montgomeryshire and Shropshire.

There is little doubt that sheep scab will again be brought under control during the next few months, and we may see the use of organo-phosphorus as well as BHC dips. The main difficulty will be to keep a most careful watch on the ports through which infected sheep may pass, and to dip thoroughly all sheep which are not intended for immediate slaughter, or even perhaps to dip all sheep as a precaution. A further thought in the back of our minds is that BHC-resistant scab mites were reported from Argentina in 1962 (Ault et.al., 1962). This is an additional stimulus to eradicate the disease before any such mite populations appear here.

It is a measure of the contrariness of work on the control of arthropods that in the British Isles we can see how warble has been virtually eradicated from Eire, although they still have some 70-80 cases of sheep scab each year, while in the United Kingdom we have a reasonably flourishing warble population but virtually no sheep scab!

CONCLUSIONS

Particular aspects of the control of ticks and other arthropods will be dealt with in the papers which follow, but some thoughts on the future may be relevant.

The latest outbreaks of sheep scab, the continuing problem of warbles, and - abroad - the huge difficulties which face cattle ranchers in ticky areas, show that we do not by any means have all the answers either to straightforward control or to the resistance problem. Arthropods have developed resistance to most major classes of insecticides, insecticidal oils being a fortunate exception, so that the value of new materials such as chlorphenamidine can be appreciated. It would not be surprising to find in due course resistance by aquatic larvae to oils, as this is only a further step from the known production of detergent-like materials which are secreted by some insects to aid the action of digestive enzymes on fat droplets in the food.

Even biological forms of control, such as the use of the "sterile male" irradiation technique or the distribution of sex attractants (pheromones) coupled with insecticides, are now no longer considered out of reach of the counter-development by the insect of some form of "resistance": flies might be able to develop a new type of pheromone, or there might be a development in parthenogenetic behaviour, already known in some species of ticks, as well of course as in some pests of agricultural crops. The sterility techniques of control have been very successful with such pests as Mediterranean Fruit Fly, but the recent setback with screw-worm in the United States has led to critical re-examination of the procedures used. Some, perhaps many, species of insects seem capable of re-colonising lost ground from very small residual populations, and this particular aspect may also bear on the slightly less than 100% control of warbles achieved in Eire.

One factor that adds to the problems of insecticide resistance is that this is not confined to arthropods, but extends to people and to various organisations. Laws are passed and social consciences stimulated so that the development of further insecticide materials becomes restricted, leading to serious shortage of the very chemicals that previously allowed the complainers access to pest-free food, whether from animals or plants. One type of future would lead to available pesticides being cast aside one by one, further efforts at control becoming ineffective or economically prohibitive and the introduction of panic measures. This line of argument has been seriously discussed at length by the President of the American Society of Tropical Medicine and Hygiene (Reeves, 1972). One could reach the stage where some decision had to be made about the use of the remaining reserves of insecticides: what would then happen in an emergency case of insecticide resistance, plague outbreak, louse-borne typhus, or cereal disease? How would priorities be decided? Would registration procedures have to be shelved? Would one country sell to another its last reserves of insecticides?

The development of new pesticides has become extremely expensive, as registration work intensifies and yet more stringent requirements have to be met (would DDT ever have been used if it had been discovered this year?); scientists using increasingly delicate techniques can now find that apparently useful materials have to be shelved because of undesirable side-effects caused by chronic feeding of minute amounts of these substances, and residues that once could not be detected by then-existing apparatus are now demonstrated in organic substances in many parts of the world. Despite these problems, I have always favoured the use of chemical insecticides at some stage in the control of ectoparasites, regardless of the outcries about the contamination of the environment - for no sane person will use insecticide indiscriminately. I think that control will always involve either complete destruction of the insect population by insecticides, or the reduction of the population to a low level by means of some bio-technique followed by completion of the programme with chemical insecticides.

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NOTES

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COCOA BLACK POD - RECENT ADVANCES IN CONTROL

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Summary Annual loss from cocoa black pod disease (caused by Phytophthora palmivora) is estimated to average about 10% of the world's crop. Incidence differs widely from year to year and between different cocoa growing regions. In the worst black pod areas 80 - 90% of pods may be lost on untreated trees. Control measures, often difficult to apply because of the nature of small peasant farms, include: hygiene, such as frequent harvesting of ripe pods to remove inoculum; planting cultivars that resist or escape the disease; and fungicidal sprays. High volume application of copper fungicides to pods from hand operated knapsack sprayers are generally favoured in West Africa, where early in the season only pods on the trunk are treated. Low volume applications to the whole canopy from shoulder-mounted mist-blowers are favoured in Bahia (Brazil) where holdings tend to be larger. Spraying is uneconomic when pods average fewer than 10 per tree, where black pod incidence is less than 10%, and when the price of cocoa is low. Some organic fungicides, including triphenyltin and dithiocarbamates are promising, but a systemic fungicide active against Phytophthora is needed to supplement prophylactic spraying. Research in epidemiology should give precision to timing and postitioning of fungicide applications, and to hygienic measures.

INTRODUCTION

Black pod disease (Phytophthora palmivora) occurs almost everywhere cocoa is grown. The world's mean annual loss from black pod was estimated by Padwick (1956) at 10% (i.e. 150,000 tons of dried beans, worth about £75 million at today's price). Opeke & Gorenz (in press) put the loss at 20 to 30%, varying according to annual severity.

Loss is probably negligible in Malaysia, Papua-New Guinea, and in the drier parts of the Ivory Coast. Loss is estimated at 17% in Ghana, and 12 to 25% in Nigeria (Filani, 1973). In Cameroon, Muller & Njomou (in press) suggest a long term average loss of 50%, and say that 100% loss is not unusual on untreated trees. Further, Muller (1973) suggests that in the wetter parts of Western Cameroon, although conditions are excellent for growing cocoa trees, P. palmivora may constitute an ecoparasitic limit to the cultivation of cocoa because reasonable control is unobtainable. In one experiment, where annual rainfall was 3.7 metres, loss from black pod was 64% after 15 applications of cupric hydroxide at 0.75% a.i.

The heterogeneity of most cocoa holdings makes disease control difficult, as also accurate measurement of gain from spraying. Bahia (Brazil) has a proportion of large plantations with regularly spaced trees that are relatively easy to spray, tend and clean. But in West Africa, where cocoa is mostly produced on small holdings with irregularly spaced trees, often beneath shade trees, control measures are difficult to apply. Lotodé & Muller (in press) have summarized methods developed in Cameroon for improving field and statistical experimentation under conditions of extreme heterogeneity in tropical crops such as cocoa.

Phytophthora-infected pods produce abundant spores. Each pod is at risk on the tree for about $5\frac{1}{2}$ months, and generations of pods overlap throughout much of the year. Infection passes easily from old to young pods on the same tree, and the infections seen at any one time are only a fraction of the pods lost for the whole season.

HYGIENE

There are many potential sources of P. palmivora in a cocoa plantation but their relative menace is not known, except that at the height of an epidemic infected pods must be the main source.

In Cameroon (Muller & Njomou, in press) inoculum coming from the soil is important in starting the annual attacks. In Eastern Cameroon, provided all old diseased mummified pods left over in the canopy and elsewhere are eliminated, the earliest infections tend to occur on pods near the base of the trunk. Later in the campaign infections occur progressively higher up the tree. This leads to the economical recommendation to spray pods on the lower 2 metres only, 4 or 5 times during the first rains (say from May to July) and twice more in September, and then to spray all unharvested pods including those in the canopy in October and November during the main rains, until the epidemic ends spontaneously with the arrival of drier weather.

There is some evidence that insects, particularly ants, carry inoculum up the tree (Evans, 1973; Okaisabor, in press). In Ghana and Ivory Coast some pods seem to become infected through the peduncle from dormant P. palmivora infections in flower cushions on the trunk.

The International Office of Cocoa and Chocolate is sponsoring a team in Nigeria to study the proportion of infections coming from various inoculum sources during the course of the annual epidemic. Results from this research should show how to time and place fungicides more efficiently, and point to the most important hygienic measures.

Practice of hygiene is an obvious control measure, easily advocated but neglected in most countries. Experiments show that to achieve good control in Cameroon it is essential to combine strict hygiene with fungicide spraying, as neither alone is sufficient.

BREEDING FOR RESISTANCE

Several countries have programmes for cocoa breeding including resistance to black pod. Some of the Amazon hybrid trees tend to have more black pod than the West African amelonado. However, seed from biclonal plots planted with two resistant parents is becoming available to some growers. Resistance appears to be controlled by dominant genes (Muller, 1973).

Breeding is also directed towards disease-escape by seeking trees that yield their crop over a short period, decreasing the overlap between pods of different ages, or trees that produce more of their crop after the wettest period.

Whatever hope plant breeding holds for the future, in the years immediately ahead we must get our cocoa from trees now cropping, and the need for fungicides continues.

CHEMICAL CONTROL

Where black pod is expected to cause less than 10% loss spraying is not considered worthwhile. When sprays are applied, as Filani (1973) points out, results are often disappointing because the job is inefficiently done.

In Nigeria 70% of cocoa is reported to receive fungicides, and the farmer is helped by a government subsidy on copper fungicide. In Bahia 2 to 4 applications between May and October seem to give useful control (Rocha & Machado, in press), but in Western Cameroon 10 to 12 applications may be ineffective. In Ghana, although much cocoa is sprayed with insecticides to control mirids, fungicides are not officially encouraged, except for trees producing seed for new plantings, or on cuttings and seedlings in nurseries. Thorold (1959) reckoned that trees carrying fewer than 10 or 12 pods per year are not worth spraying. Newhall (1969) puts this limit at a yield of 500 kg/hectare (say 450 lb/acre) of dried cocoa beans. Most of the amelonado plantations in Ghana yield less than this.

The situation in Ghana may change when high-yielding cultivars are developed and improved agronomic practices become widespread. Amazon hybrid cocoa in Ghana, with proper spacing, fertilizers, mirid control and decreased shading, can yield several times the limits suggested by Thorold or Newhall. Fungicide spraying should become more profitable on improved cocoa. Indeed, it will become increasingly necessary because the more productive trees not only have more black pod than low yielders, but also have a greater proportion of pods infected - probably because the fungus spreads more readily when pods are close together.

Spray costs have to be kept down. In Bahia spraying is recommended only on those areas on each holding where black pod attack is early and severe. The positions of these 'foci' (covering perhaps 15% of the cocoa area of Bahia) are well-known to individual farmers.

On the small farms in West Africa sprays are usually applied at high volume from a knapsack sprayer. On the larger holdings in Brazil sprays to trunk and canopy are often applied low volume by shoulder-mounted mist-blowers which can reach higher than knapsack sprayers. The choice of more expensive machines in Brazil is partly determined because the trees there produce most of their pods higher up than those in West Africa.

Spraying from aircraft, useful with bananas, seems useless with cocoa because the pods are deeply hidden below the tops of the canopy and protected from overhead sprays. Furthermore, the mineral oil, atomised successfully against banana leaf-spot, has proved useless against P. palmivora on cocoa.

Copper fungicides are still almost exclusively used in farm practice, but instead of Bordeaux mixture there is now a choice between cuprous oxide, cupric hydroxide or oxychloride. Besides comparisons of copper formulations, rates, applications etc., other chemicals are being tested. The triphenyltin fungicides give as good or better control than copper except in the wettest areas. Now interest is turning to dithiocarbamates. In laboratory tests in Nigeria, Gorenz (1972) found orthodifolatan promising. In field tests in Cameroon, Muller & Njomou (in press) found 0.25 or 0.30% orthodifolatan as good as the standard copper oxychloride spray at 0.5% a.i.

A systemic fungicide, active against Phytophthora, would be useful in controlling pod infection, and possibly also against stem canker and dormant infections in flower cushions. But systemics could pose a bigger problem with toxic residues than do traces of tin or copper on the outside of a massive throw-away husk. Among systemics, Asare-Nyaka (1972) found aureofungin (Hindustan Antibiotics) promising in laboratory tests, but only at 10 to 100 times the recommended concentration.

Fungicides could also be applied to the ground around trees to destroy inoculum aestivating in the soil. Investigating this, Okaisabor (1972) reported that Perecol and orthodifolatan both usefully delayed the onset of the black pod epidemic, and were more effective in soil than copper preparations.

Many additives have been tested to improve spread or adhesion of copper fungicides to the waxy pod surface. Newhall (1969) commented that the most successful additive for copper fungicides is a good insecticide. Filani (1973) states that spraying mixtures of fungicide and insecticide is increasingly popular among peasant farmers in Nigeria to save labour and obtain a better control of black pod (acting perhaps by controlling insect vectors of Phytophthora inoculum).

Until stable resistant cultivars or hybrid seed are developed and distributed widely, technical advances in cocoa cultivation should make it increasingly worthwhile to spray against black pod, and interest in fungicides should increase as their application is more closely linked with epidemiology.

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COFFEE RUST IN SOUTH AND CENTRAL AMERICA

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It has long been recognised that coffee leaf rust caused by *Hemileia vastatrix* represented a serious threat to coffee in S. and C. America where the varieties of coffee grown are all susceptible and conditions are very suitable for the development of the disease. It was discovered in Brazil in January 1970 and had spread throughout the coffee areas of that country by the end of 1972, despite attempts to contain it. Because there are over 2 million hectares of coffee in Brazil and some 6 million people are dependent on the crop it is not difficult to appreciate the significance of the situation. The importance to the pesticide industry is also considerable as the only immediate practical method of control is by using fungicides, generally copper-based, applied at a rate of about 30 kg/ha annually.

The whole of Latin America is now threatened by the disease where some 5 million hectares produce up to 60 per cent of world coffee exports and many of the countries are largely dependent upon coffee sales for their foreign exchange earnings, employment and social structure.

There are many aspects of this situation which could be considered. The way in which the disease reached Brazil will probably never be known, but the event has already triggered off some controversy about the role of wind in the long distance dissemination of the fungus. The existence of the disease in Brazil presents formidable plant quarantine problems for the other coffee producing countries of America with inevitable consequences to international trade. The disease is also responsible for a much needed stimulation of research into coffee technology in C. and S. America and for renewed investigation into the biology and control of *Hemileia vastatrix*, despite the fact that the subject has been studied intensively for over 100 years, and has left a challenging volume of literature for the aspiring reviewer.

Those who are familiar with the situation might feel that too much has been written about the appearance of the disease in America and the possible consequences and that perhaps too many uncoordinated visits by international 'advisers' have already been made, but there can be no doubt that this latest extension in the geographic range of the disease is of great economic importance. In the context of this conference we can confine attention to some aspects of the chemical control of the disease, firstly as a current problem in Brazil and secondly as a potential problem for the rest of America.

Accepting that fungicide application was the immediate practical solution to controlling the disease in Brazil the questions to be answered were what to spray, when to spray, how to apply the spray and what were the economics of spraying. A considerable programme of research and field experimentation was required to answer these questions and is now in progress but of course in such a situation it is sensible to make the best use of available information. Programmes of fungicide spraying could be based initially on the currently accepted principles of spray timing, fungicide quantities and spray application methods as, for example, elaborated in East Africa.

Several different fungicides can be used but those based on copper have usually been found to be the most effective and often the cheapest. A disease epidemic shows three distinct phases; a trough phase, then a rapid increase rising to a peak level of infection, followed by a decline in the number of infected leaves on the trees due to rust induced leaf fall. With well marked rainy seasons the disease increases from the trough phase at the beginning of the rains and maximum control results from a series of sprays applied just before the beginning and during the early period of the rains. The effects of rainfall intensity and distribution, temperature, leafiness of the trees and amount of residual spore inoculum have been well documented, so it is not difficult to suggest provisional spray timing programmes. Water based sprays can be applied efficiently at, for example, 135 l./ha (12 gal/ac) with motorised knapsack mistblowers, 270 l./ha (24 gal/ac) with hand powered sprayers or 225 l./ha (20 gal/ac) with tractor powered sprayers. The quantity of fungicide usually recommended is 5.5 - 7.7 kg/ha (5-7 lb/ac) per application and three or more applications may be necessary. The economics of applying such a programme of sprays has, of course, to be studied locally and not too much help is available from published data to suggest any clear relationship between disease level and yield. Much will depend on the general level of management, the potential yields and the production costs but in Brazil even the most conservative estimates suggest that in order to make spraying feasible a yield of not less than 600 kg/ha of clean coffee is necessary.

This was the basic information on control of the disease when it spread through Brazil. The trend in E. Africa had been to reduce spray volumes and fungicide quantities to a minimum compatible with good control but from about 1964 onwards coffee berry disease (caused by Colletotrichum coffeanum) in Kenya became the most pressing problem and called for somewhat different techniques of control and greater quantities of fungicide in higher volumes of water. It is therefore from Brazil that new innovations can be expected to reduce the costs of fungicide application for rust control.

Because of the large areas under coffee there is a great interest in low volume and aerial spraying. Previous experience had not demonstrated that spray applications of less than 90 l./ha, either from the ground or the air, could result in satisfactory rust control but every attempt is now being made to reduce this as water supply can be a critical factor in field operations. Two approaches are being made; the use of fungicide in low volume oil water emulsions and dusting. The actual application of fungicides in oil water emulsions is well understood from experience with bananas but its effect on coffee rust is a new problem. In the case of bananas not only does the oil serve as a convenient fungicide carrier but it has a fungistatic effect on Mycosphaerella and can give effective control of Sigatoka disease even without the addition of fungicide. Under certain circumstances it can be phytotoxic and by affecting photosynthesis and transpiration can reduce yield if applied in excessive quantity. It is not yet known to what extent oil application to coffee has a fungistatic effect on H. vastatrix nor what its effect on the plant is. It is also important in coffee rust control for the fungicide to reach the underneath of the leaves. This can either be achieved by directing it there in the first place or by relying on redistribution of the fungicide by rainfall. With low volume spraying, particularly from the air and in densely planted and very leafy coffee, as is common in Brazil, it is difficult to achieve under-leaf cover, and the effect of oil on the possibility of redistribution remains to be studied. Notwithstanding these problems, preliminary results suggest that control of the disease can be achieved by using knapsack mistblowers to apply copper fungicide in oil water emulsions (e.g. 5 kg 50 per cent copper oxychloride in 6 litres water, 7.2 litres oil plus emulsifier per hectare). Lower volumes applied with the battery operated ULVA equipment have not been successful.

Preliminary work in Brazil also indicates that dusting at 35 kg/ha with a 7.5 per cent copper formulation or at 20 kg/ha using one with 20 per cent copper can give as good control as Bordeaux mixture. In E. Africa early work with dusting was not very promising, probably because of its lack of tenacity in the face of weathering but the method is clearly worth further investigation in areas where the provision of water is particularly difficult.

Although lower volume spraying and dusting techniques are being developed their success in the field will depend on skilled application. To achieve this in countries where previous experience in applying fungicides to coffee is slight will require much extension work and training. At the same time it will be essential to improve cultural practices especially spacing and pruning to ensure that treatments are effective and economically feasible. It is tempting to carry out field experiments with new techniques only on specially selected and easily treated coffee but it is more difficult to translate them to general use.

Much of the coffee in Brazil is amenable to aerial spraying or could be treated by equipment drawn by tractors or animals. In most of the other countries of the continent coffee may be heavily shaded and the crop often grows on steep mountain slopes. Here only motorised or hydraulic hand directed sprayers can be used and even then topography and close planing may pose difficulties.

The potential costs and problems of rust control in these countries makes keeping the disease out for as long as possible of prime importance. The most interesting developments are the major campaigns such as that in Colombia to impress on the public and coffee growers the importance of plant quarantine and the early recognition and eradication of the disease should it occur. Regional quarantine organisations are giving rust high priority and despite limited resources are doing excellent work. A successful eradication will depend on early detection which is difficult at low incidence levels. It is for this reason that extensive educational campaigns emphasising the importance and recognition of the disease are so important and why there is interest in sample survey systems which can be used to gather data on coffee production as well as checking for the presence of rust.

In the event of the detection of a new outbreak of rust the problems of eradication are complex. Legal provisions have to be made and problems of a political and social nature have to be considered as well as the question of indemnity. The physical destruction of the coffee also presents problems as does the question of how long it will be feasible to attempt to contain the disease. National activities need to be integrated with a regional and international approach and a clear and practical plan of action must be fomulated in advance. Some work has already been done simulating the eradication of infected coffee. If defoliants are used they must completely desiccate the foliage and ensure the destruction of the fungus, otherwise the fallen leaves will still harbour viable spores and be difficult to deal with. Paraquat has proved to be effective in this respect and operational research into the burning of the trees either in situ or after cutting is also being carried out.

If the disease becomes established in the Andean and Central American countries very real problems of control will arise and apart from the factors already mentioned the logistics of providing fungicides, machinery, water and training courses in spray application will be formidable.

A new era of research and extension activities related to coffee rust has begun and presents an important challenge to all concerned with crop protection.

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BANANA DISEASES IN THE WINDWARD ISLANDS

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Summary Crown rot is the most serious post-harvest disease of bananas in the Windward Islands. Fungi most commonly associated with this disease were *Colletotrichum musae* and *Fusarium semitectum*. There were no serious pre-harvest fruit diseases. Pre- and post-harvest rots were controlled by benomyl (250µg/ml) thiabendazole (400µg/ml) and experimentally by related compounds. Sigatoka leaf spot, the most serious field disease, is controlled by aerial spraying with oil. The leaf spot disease forecasting devised by French workers in Guadeloupe operated effectively at locations in the Windward Islands. In a non-replicated trial carried out over one year in St. Lucia 8 sprays of benomyl/oil gave equal control with 20 sprays of oil alone. There are no other serious field diseases of commercially grown bananas in the Islands.

Sommaire La pourriture des coussinets est la maladie la plus grave des bananes aux Iles du Vent. Les cryptogames les plus associees avec cette affection sont comprises de *Colletotrichum musae* et *Fusarium semitectum*. Il n'y avait pas de maladies serieuses d'avant-recolte. Les pourritures d'avant - et d'apres - recolte etaient controlees par le benomyle (250µg/ml), le thiabendazole (400µg/ml) et dans des essais, par des composes derives. La maladie de Sigatoka, l'affection la plus grave dans les plantations, est controlee par traitements aeriens d'huile. Le systeme de prediction invente par des techniciens francais en Guadeloupe etait efficace aux locations aux Iles du Vent. Dans un essai non-repete affectue au cours d'une annee en Ste. Lucie, 8 atomisations de benomyle/huile a donne un controle egale a cela de 20 traitements d'huile seule. Il n'y a pas d'autres maladies serieuses des bananes commerciales aux Iles.

INTRODUCTION

The Windward Islands, comprising Grenada, St. Vincent, St. Lucia, and Dominica are situated in the South Eastern Caribbean. They are mountainous, of volcanic origin, and lie between 12° and 16° north of the equator. Annual rainfall.

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averages about 2500 mm but varies between the islands, and with location within each island: there is a dry, relatively cool season from January until April. Mean temperatures range from 20°C to 31°C.

Bananas are the major export crop from the Islands. They account for 85% of the export earnings of St. Lucia, 78% for Dominica, 56% for St. Vincent, and 28% for Grenada. Almost half the export crop is produced by peasant farmers on small holdings, usually on steep hillsides. The remainder come from large estates of up to 400 ha in area, which are mostly situated in relatively flat valleys.

Marketing of the crop is the responsibility of Windward Islands Banana Growers Association (WINBAN), a parent body linking the Growers' Associations of the Four Islands, and which is responsible for the research conducted at the WINBAN Research Centre in St. Lucia.

Export production rose from 97000t in 1959 to 200,000 t in 1969, but fell to 126,000 t in 1971 due to adverse weather conditions. The increase in production between 1959 and 1969 was not accompanied by an improvement in the quality of the fruit. (Phillips & Spector, 1969; Phillips 1970). Adverse agronomic conditions, mechanical damage caused by difficult handling conditions, disease, and the low yields obtained all present problems.

This paper examines the status of disease problems in the industry and summarises two years work in the Windward Islands.

FRUIT DISEASES

a) Pre-harvest

Pre-harvest fruit diseases are not common in any of the Windward Islands. Cigar-end, caused by Verticillium theobromae was found only on four occasions on individual bananas nearing maturity. The fungus itself was constantly to be found on the withered flower remains of bananas but apparently the conditions necessary for widespread infection do not occur.

A flower end rot associated with Fusarium semitectum was found on about 0.1% of bunches harvested at the WINBAN Research Farm. Often several adjacent individual bananas on a bunch were affected. The symptoms of this disease were similar to Cigar-end but the typical "cigar ash" appearance was lacking. Superficial fungal growth was less and the rot itself was wetter than Cigar-end. Pathogenicity tests confirmed that F. semitectum was the causal organism and this fungus was also invariably to be found on decaying flower remains.

A third flower end decay caused by Botryosphaeria ribis (Reichert & Hellinger, 1938) was recorded. This disease appeared occasionally in the wet season (May to December), its frequency being similar to that of the flower end disease caused by F. semitectum.

Colletotrichum musae was isolated from the skin of apparently uninfected immature green bananas. This fungus was isolated from the surface sterilized skin of fruit as early as one week after the bunch had emerged from the pseudostem, presumably from latent infections (Griffee and Burden, in press). In this study such infections were controlled by four pre-harvest sprays of benomyl at a concentration of 1000 μg/ml a.i.

As all major post-harvest diseases of the bananas produced in the Windward Islands can adequately be controlled by post-harvest treatment with either benomyl or thiabendazole there appears to be no need for field application of fungicide to control pre-harvest fruit infections, which are relatively rare and of little or no commercial importance in the Windward Islands at the present time.

In the course of the investigations into possible latent infection by C. musae, a benomyl resistant strain of this fungus was isolated from bananas which had received pre-harvest benomyl sprays (Griffee 1973). It retained its resistance through several subcultures on fungicide-free PDA, suggesting a permanent nuclear change. This illustrates a hazard in using the same fungicide (benomyl) in the field for Sigatoka control as in post-harvest treatments for fruit rot control.

b) Post-harvest

(i) Crown rot

The crown rot complex is now the most important disease affecting bananas during transport and ripening (Simmonds 1966; Meredith 1971; Wardlaw 1972). This has been associated with the change in commercial practice from shipping whole bunches to the shipping of bananas as hands packed in fibreboard boxes. This disease has contributed significantly to the incidence of poor quality bananas exported from the Windward Islands to the United Kingdom (Bailey et al. 1970). Crown rot is well documented as a disease complex and the range of organisms associated with the problem in various countries has been reviewed by Meredith (1970). A monthly survey of the fungi associated with crown rots made over two years in the four Windward Islands showed that, of a total of 6,264 isolations made, the relative proportions of fungi recovered were: Colletotrichum musae 35.8%. Fusarium semitectum 26.8%, Verticillium theobromae 8.1%. F. moniliforme 5.5%. F. graminearum 2.3% Botryodiplodia theobromae 1.9%. Nigrospora sphaerica 0.7%, and other fungi 0.9%. Of these isolations 24.9% gave no fungal growth; mixed cultures, mainly a combination of C. musae and F. semitectum totalled 6.9%.

The pathogenic status of these fungi, &of F. oxysporum, and Ceratocystis paradoxa was tested by inoculating them into surface-sterilized cut crowns of banana hands. On re-isolation when the resulting rot had penetrated 5 mm into the crown from the cut surface or when it had penetrated to the pedicels there was a major percentage recovery of each of these fungi (Griffee, in press). The status of C. musae and C. paradoxa as wound pathogens was confirmed, and that of F. semitectum and F. graminearum established. F. moniliforme and F. oxysporum also appeared to be pathogenic, and V. theobromae and N. spaerica weakly pathogenic. Naturally occuring infections of F. semitectum confused the results obtained from these last four fungi. Mixed inoculations of F. semitectum with C. musae or V. theobromae did not cause more rapid rotting than separate inoculations of these species, and in all mixed inoculations F. semitectum was the dominant organism recovered.

Commercial control of the crown rot complex is achieved by the application of fungicide to the dehanded bananas after they have been washed. The dehanding cut must be smooth and clean so as to avoid a rough surface and washing must have proceeded long enough for the flow of latex from the cut surface to have ceased before the fungicide is applied. Effective fungicides are thiabendazole, first used in Australia (Burden, 1967; Scott and Roberts, 1967) and benomyl, first used in Taiwan (Ogawa et al, 1968). Either of these is currently employed in the Windward Islands; thiabendazole at 400 μg/ml or benomyl at 250 μg/ml.

These two materials were used as standards in trials comparing the effectiveness of more recently introduced fungicides for crown rot control (Griffee and Pinegar, in press). Primary screening was done at the WINBAN Research Centre. Hands of "Robusta" bananas at harvest maturity were washed; sprayed with the test fungicides at varying concentrations; and packed in fibreboard boxes using polythene film liners to prevent abrasion. Packed cartons were then subjected to simulated shipping and ripening conditions (ambient temperature for 24 hr., followed by 12 days at 13°C, then ripened at 17°C, initiating the ripening with ethylene gas at 1000 p.p.m. for 24 hr.). The hands were then assessed for crown rot when at stage 5 of ripeness (von Loesecke, 1949), using ratings on a 0 to 4 scale indicating the depth of penetration of the rot from the cut surface of the crown into the pedicels of the individual fruit. From this preliminary trial three fungicides (all benzimidazole derivatives) were selected for further investigation, "Bavistin"; methyl thiophanate; and experimental fungicide DAM 18654. Others, 'Calixin', 'Delvocoat', 1:3 butylene glycol, 'Embathane', 'Triforine', Experimental fungicide R 70881, and DS 9073 were found not to give satisfactory control of the disease.

A shipping trial comparing the three selected fungicides at 250 and 400 µg/ml with benomyl and thiabendazole at 250 and 400 µg/ml respectively was carried out. Bananas were shipped to the United Kingdom where the fruit was ripened under commercial conditions and assessed for crown rot.

Fungicides for control of crown rot of bananas.

Treatment	Concentration a.i., (µg. per ml.)	Crown rot Score (mean of 240 hands)
benomyl	250	·82
thiabendazole	400	·87
bavistin	250	·78
"	400	·68
DAM 18654	250	1·13
"	400	·87
m-thiophanate	250	·90
"	400	·95
control	-	2·33

L.S.D. at 5% probability = ·09

Bavistin at 400 µg/ml was significantly better than other treatments and DAM 18654 at 250 µg/ml was significantly less effective.

The results of the primary screen and shipping trial were in general consistent with in vitro studies carried out on these fungicides at the Tropical Products Institute with the exception of DS 9073 which was very active in vitro but not in vivo (Griffee and Pinegar, in press).

The control given by each treatment in the shipping trial was commercially acceptable: a crown rot score of 1.5 represents rot which can be trimmed off by the marketing company at no quality loss. It is unlikely that the application of fungitoxic chemicals will eradicate rot at the source because of the deep seated latent infections that occur (Simmonds, 1963) and the distance which spores may be drawn into the crown tissue during dehanding and washing (Greene & Goos, 1963). Application of pesticides is however governed by food additive laws, and residue levels at the time of reaching the customer must be strictly controlled. However, the correct use of any of these five chemicals will give satisfactory control provided that premature ripening caused by Sigatoka disease or late harvesting is avoided.

Problems which occur in the application of these fungicides are those commonly associated with the application of wettable powder by spraying or dipping, both of which methods are used in the Windward Islands. Trays of bananas (6 to 9 hands) are sprayed using a hand operated knapsack sprayer or a small motorised unit and the excess suspension drains to waste through perforations in the tray. The advantage of this system is that a constant concentration of fungicide should be applied. Disadvantages are that the powder readily settles out, spray nozzles block, and to drench the bananas thoroughly is a time consuming process, and operator hazards occur, in which whole trays of fruit may be missed or inadequately sprayed.

Alternatively, banana hands are manually dipped into bowls containing about 40 litres of fungicide suspension. This method has the advantage that complete coverage of the hands is ensured. Disadvantages are that the fungicide powder quickly settles out of suspension and the suspension is also diluted by the dipping of hands wet from the wash tank (this dilution rate is not constant and replenishment is difficult to calculate); it is a slow process; the handling of the fruit can lead to mechanical damage; and operator hazard may result in incomplete immersion of the fruit.

A simple 'cascade' machine was developed in order to overcome these problems. The suspension was drawn from a 50 l tank having the take-off at the lowest point and forced by a centrifugal pump onto a deflector plate to produce a continuous sheet of suspension slightly wider than a tray of bananas. The trays of fruit moved by gravity down a roller conveyor enclosed by splash guards, which ensured that the trays of fruit passed through the cascade of suspension. Excess suspension draining from the perforated trays was returned via a drainage shute to the reservoir. Turbulence caused by the suction of the pump proved adequate to keep the fungicide in suspension. Replenishment requirements due to the depletion effect of the bananas on the original suspension were calculated for each one hundred boxes of fruit treated. Commercial trials showed that the 'cascade' system gave significantly better crown rot control and more even fungicide residues on fruit than the other methods. Certain fungicide formulations (e.g. Mertect 340), could not be used in this machine as they produced excessive foam in which the fungicide tended to accumulate. However, Tecto 90 (a TBZ formulation used in Australia), benlate and 'Bavistin' did not cause appreciable foaming and so avoided this depletion effect.

(ii) Anthracnose

The second post-harvest disease problem is caused by anthracnose (C. musae), either directly as a result of the development of pre-harvest latent infections (Dastur, 1916; Wardlaw, 1937; Simmonds, 1941; Chakavarty, 1957; Wardlaw, 1972; Griffee & Burden, in press) or indirectly by infection of wounds (Meredith, 1960), particularly those caused by mishandling of the fruit leading to pedical damage, skin bruising, and abrasion of the finger ridges rubbing against the fibreboard boxes. These latter give rise to the lenticular type of wound infection, described by Meredith (1960). Control of anthracnose is achieved by careful handling of the fruit and correct use of fungicide as described for crown rot.

(iii) Other fruit diseases

Botryodiplodia theobromae and Ceratocystis paradoxa caused extensive rotting as wound parasites on fingers, but their occurence was so rare as not to be of economic importance. There were no other serious post-harvest fruit diseases.

(iv) Origins of Infection

C. musae spores are commonly found in washing tanks of banana boxing plants and these can constitute a source of infection (Greene & Goos, 1963; Meredith, 1971). Decaying bananas in the field and around boxing plants are invariably infected with C. musae in the Windward Islands. Drosophila species feeding on these rotted fruit not only transmitted the fungus by contact, but evidence was obtained that spores were transmitted through the digestive system of the insect & microscopic examination of the digestive tract and frass revealed intact C. musae spores. This could account for some transmission of anthracnose during dry weather. The importance of a high level of field sanitation in control of post-harvest banana diseases has been emphasised by Simmonds (1941) and Meredith (1962).

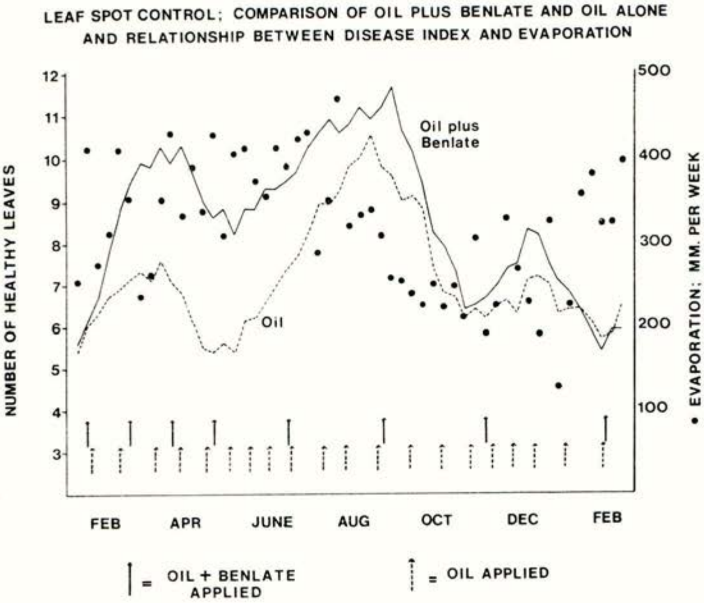
Leaf Diseases

Sigatoka leaf spot caused by Mycosphaerella musicola is the most serious disease of bananas in the Windward Islands and has been reviewed by Meredith (1970). Initial infection on the leaf is seen as pale brown flecks which develop into spots. These coalesce to form large necrotic patches and in severe infection the leaves are killed. The infection cycle from the initial deposition of conidia to the production of new fruiting bodies takes between 14 and 100 days depending on the temperature and availability of moisture. Control is currently by application of agricultural spray oil (Guyot & Cuille, 1956), which costs St. Lucia alone about EC$½m per year (£104,000). Application is mainly by aircraft but some inaccessible mountainous areas have to be sprayed from the ground with motorised knapsack sprayers. Sprays are normally applied at fixed intervals, but there may be seasonal variations based on experience of weather conditions. However, inadequate knowledge of the etiology of the disease often resulted in a high disease incidence, low bunch weight, premature ripening of the fruit, and increased susceptibility to post-harvest disease.

Two approaches were adopted to solve the problem: extending the effective time of applications by adding a systemic fungicide to the oil; and forecasting disease outbreaks, using meteorological conditions and disease ratings, thus preventing infection by early spraying.

Two 20 ha plots of 'Robusta' bananas in the Roseau valley of St. Lucia were scored for disease severity using the method of Stover & Dickson (1970). One plot was sprayed with oil at 15 l per ha and the other using oil at the same rate plus 250 gm of Benlate per ha (Melin, 1970). Weekly disease ratings continued for one year. During this time 20 cycles of oil and 8 of oil plus Benlate were applied (Fig. 1).

The level of disease control over the full period of observation was approximately equal for the two treatments, the Benlate/oil mixture being slightly better during the first six months. In the second half of the period, that is the wet season, the degree of control fluctuated when applications were sometimes late due to poor flying conditions. A replicated trial continuing over a longer period would be necessary to establish the relative merits of the two spray régimes.



A disease forecasting system being developed by Institut Francais de Recherches Fruitieres Outre-Mer (IFAC) in the French Antilles is based on weekly measurements of evaporation from a Piche evaporimeter. High weekly evaporation indicates unfavourable conditions for disease development giving relatively long intervals between spray cycles; under conditions of low evaporation more frequent cycles become necessary. A temperature factor and the number of hours of relative humidity above 90% during the week are also considered (Meyer & Ganry, 1971).

Forecast stations were erected in several large, uniform areas of bananas in the Windward Islands. Before forecasting started it was necessary to reduce the inoculum potential of the disease by fortnightly sprays of oil. The system initially gave very satisfactory results, however, due to unsuitable weather for application, and faulty application of oil, control deteriorated during the wet season. The problems were overcome and control subsequently improved.

In a trial in the Roseau Valley in St. Lucia, treating evaporation as the cause of variation in the number of healthy leaves, both Benlate and oil treated plants gave significant correlation. From 0 to 7 weeks the regression coefficient increased from 0.21 to 0.69, and from 0.0 to 0.57 with benlate and oil respectively, showing that a relationship exists between the Piche readings and subsequent disease intensity, and that the system has a potential use in disease control.* Considerable further work needs to be done, but if a method can be found for the economical use of oil alone, a substantial saving will be made. The systemic fungicides are too expensive and, further, may encourage the development of resistant strains.

The only other banana leaf disease recorded in the Windwards is a leaf spot caused by Cordana musae, which is of no economic importance.

Root Diseases

Bacterial head rot caused by Erwinia caratovora (Stover, 1959; Lacey, 1971) was of sporadic occurence in the Islands. The disease is thought to infect the corm through wounds in planting material. It extends into the lower part of the pseudostem causing rotting, and in severe cases the plant topples. As noted by Lacey in Jamaica (personal communication) the disease may not recur on land previously containing it, probably because critical conditions are necessary for infection. It is not of economic importance.

Vascular Diseases

Both race 1 and 2 of Fusarium wilt (F. oxysporum, F. cubense) were recorded, but the main export cultivars grown are resistant to the disease, which is therefore of no economic importance.

Systemic Diseases

Heart rot (infectious chlorosis) caused by Cucumber Mosaic Virus, was recorded in two per cent of a 50 acre planting and sporadically elsewhere. It is not common enough to cause concern in the Windwards, although in Martinique it destroyed a substantial planting. Roguing of diseased plants is believed to prevent its spread.

Discussion

In comparison with most other major banana producing countries the spectrum of economically important diseases affecting export production in the Windward Islands is relatively narrow, but the essential pre- and post-harvest disease control measures represent a major proportion of production costs.

The only serious field disease encountered was Sigatoka Leaf Spot. Post harvest disease problems were confined to the crown-rot complex and infections developing from other post-harvest fruit injuries. Other major diseases of bananas, such as Black Leaf Streak, Johnston Spot. and Moko disease were not found in any of the four Islands. Should any of these become established, the combined effect of increased losses and more costly control measures could prove crippling to the banana industry.

* See Fig. 1.

The two year survey conducted in the four Islands to identify the spectrum of pathogenic fungi involved in post-harvest fruit rots did not reveal other than the range of organisms already recorded on bananas.

Adequate commercial control of both field and post-harvest diseases can be achieved by the application of established control measures.

The isolation of a strain of C. musae resistant to benomyl emphasises the need for the development of fungitoxic materials other than those based on benzimidazole derivatives, particularly in view of the increasing use of benomyl as a field spray for the control of Sigatoka disease. A benomyl resistant mutant of the Sigatoka organism has been produced under laboratory conditions (Fourcade and Laville, 1973).

The development of a water soluble anti-fungal formulation would greatly alleviate the difficulties which are experienced in the application of suspensions of wettable powders.

Further work is required to develop the application of disease forecasting in the Sigatoka disease control programme in the Windward Islands.

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PROBLEMS CONCERNING THE PESTICIDE INDUSTRY

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Summary On the major issue of whether the pesticide industry is doing a good job for the human community, we have neither doubts nor obvious problems at present, and we can probably continue this broadly satisfactory position in future years. Nevertheless, there are problems to be faced. There is need to make sure that the industry's sales and profits are sufficient to maintain increasingly difficult and expensive R. and D. for future needs. One can see and pleads the advantages of active steps towards harmonisation or regulatory requirements multi-nationally, starting perhaps with EEC: the value of early notice of inevitable change in agricultural cropping policies: the logic of not rushing into legilative changes until a trial period has confirmed feasibility: the scientific non-validity of minor official trials still practised in a number of countries: the great value to industry of early permission to sell limited or very limited quantities of a new product, as a part of its technical and economic evaluation: the desirability of including all pesticidal uses within one coherent scheme for registration or clearance, acrossDepartmental barriers: the future importance of international organisations in helping to overcome international problems: the value of periodic strategic discussions on the best areas for industry or official research: the need, especially within industry, for still greater efforts on safety measures built-in to our products, packages, and distributor systems; the value of the industry's Trade Associations enquiring into important local accidents or incidents involving pesticides: and finally the need to make sure that our pesticide manufacturing and usage programmes do not harmfully contaminate our surroundings, especially water courses. Most of these suggestions involve joint Industry/Government cooperation, and I believe that the maintenance of that cooperation in thought and action is the clue to most future progress, in any and every country.

The title of this paper was chosen when exactly what was to be said was not immediately important. But one cannot observe and to some extent participate for twenty years in the growth of an industry without being conscious of important areas of anxiety, or difficulty, disappointment, encouragement or success. First, however, I must issue the usual disclaimer clause, that what I say will be predominantly my personal views, as I have no brief to speak for this large international industry, which has no single voice.

I will start by making clear that there is one major matter on which there is no concern within the industry, or should not be. That is the overwhelming technical success of its application of chemical science to agriculture, and of the contribution which its discoveries are making and will continue to make to agriculture, public health and personal environment of the present-day community.

I was one of those who received his tuition, in my case in agriculture and in medicine, in the interwar period of 1920-40. It is a matter of almost amazed, gleeful surprise and pride to read again, in the text-books of agriculture, horticulture and medicine of that period, the advice and instructions given on the control of pest organisms attacking crops, stored foods, animals or man. In one generation, we have moved to entirely new perspectives in what can be done when one major industry moves to the aid of another, and I believe the history books will duly record that progress. Secondly, it is proper to say that there is no significant problem in the notification, safety clearance and approval schemes as they operate in this country, again an important success story. Nevertheless, progress both solves and creates problems, and if we wish the pesticide industry's role to be fully maintained, we must periodically look at the international situation dispassionately, so that we stay on track.

I think there will be few surprises in what I have to say to those who are already fully involved members of the industry, because they are the sort of issues which arise at almost any company's management meeting when future policy matters on its pesticide activities are discussed, or when a possible new project is being scrutinised bit by bit to see if it is really alive, or dead, or dead but looking healthy, or healthy but looking dead.

FINANCE

I will start with the issues concerning the pesticide industry as a financial problem, for the first and biggest problem of any pesticide company, or agrochemical division of a company, is to return a profit and prospects which attract investors, where profit implies return on capital investment, and ultimately earnings per share. We are all now old enough to realise that in such matters there really is no Santa Claus, and that the maintenance of progress and investment in pest control internationally will basically depend on how attractive pesticide firms are to the investing company, or public or institutions.

The 'survival kit' for a firm in the pesticide industry is a steady, even if intermittent acquisition and marketing of profitable new products. The smallest firms rely on acquiring ready-to-use products: the medium size firms formulate or even manufacture some of the products or new variants themselves: the larger firms seek also to invent new chemicals, manufacture and formulate them, and license them out to the smaller firms - a familiar biological situation applied to a basically financial and logistic problem. These procedures have since 1950 introduced new products much faster than old ones died out, so the market now has ten or more times the number of effective products than 20 years ago. New products have also been introduced faster than the total market has expanded, so market penetration of marginal products is more difficult. Really major new products now have to possess convincingly outstanding properties, such as hitherto unachieved selectivities, or multiple utilities, simplicity in use, use in better agricultural systems, safety in use, or some other very practical appeal to a very large number of growers.

THE LONG TERM GAMBLE

Due to these tightening standards for a really major new product, there is a decreasing success rate per unit effort of inventive chemistry and biology. More years are taken to innovate, select, prove and register products which match up to market requirements, or justify the capital investment of a manufacturing plant, which can rarely be used for any other production purpose. The period of negative cash-flow on a project, i.e. the period when one is spending more money than is coming in on the product, lengthens progressively, except in very rare cases. It may indeed now be a long wait of up to 12 years before sales of a new chemical have recouped all the costs of development. Meantime, inflationary trends show that one must allow on average about 8% more expenditure per annum to carry out the same work at the same pace, and 10% per annum to be keeping up with the increasing sophistication of research methods and equipment we have to use to satisfy testing requirements. A crop protection chemical first synthesised in some laboratory on this particular day in November 1973 is most unlikely to be discussed from this platform as an important research product until 1977, most unlikely to be sold widely until 1980, and most unlikely to show a net positive cash flow, i.e. to have cleared its debts, until 1983. Little wonder that the pesticide industry exhibits its due share of failures, acquisitions, mergers, re-organisations aimed at higher market penetrations, licensing arrangements and other manifestations of financial turbulence. Little wonder also that our official colleagues are amazed when they hear of forward R. and D. and financial planning by a firm for the next 5, 10 or 15 years. Most applied biologists quote the 21 month gestation period of an elephant with some awe and respect; they should look a little nearer home in future.

KEEPING ECONOMIC AND R. & D. VIABILITY

What can be done to help ensure that these inescapable trends do not reduce the availability of those future new products needed to replace further shrinkage of agricultural labour forces, or to control difficult old or new problems, or to improve standards of safety in use ? The clue is quite simply in the word money, and more explicitly, the expansion of profitable sales. External pressures to reduce prices are ill-advised and short-term thinking. Panicky reductions of prices within the industry, beyond the scope of brief commercial gamesmanship, are asking for trouble. Recommendations to growers to take a little risk and use low-price semi-adequate measures or products, except in grave crises of farm finance, are almost certain to cause eventual repercussions on new product availability. There may be situations ahead of us where Governments with major pest problems in their national agricultural production or crop conservation could logically and justifiably subsidise specific research programmes within industry, or subsidise the usage of specific chemicals, on the principle of short term modest expenditure for longer-term major national gains. Given a stable and adequate income, the chemical industry can continue to produce a flow of valuable new pesticides, despite the increasing difficulties. I suggest that Governments have a certain direct financial responsibility to ensure that their present and future national pest problems are solved, rather than leaving most of it, as in the recent past, to the chemical industry.

THE NEED FOR HARMONISATION OF THE RULES

That is one aspect of my own increasing feeling that the maintenance of progress in our chosen field is a matter of increasing team work between Governments and industry. One of industry's problems is that individual Governments are set up on a national basis, and have an inherent insularity which has in the past been valuable, but must in the future be modified by an increasing acceptance of international coordination. The pesticide industry and its major companies simply have to be international in all thought and actions, especially those of European countries whose home bases only provide a small fraction of the World's total pesticide market, for comparison with the USA firms' home market of 50% or more of World pesticide usage. One of the most frustrating components of new product development on a multi-national basis is the almost total absence of any plan or attempt between Governments to draw up schemes for uniformity of registration requirements. With very few exceptions, such as the Benelux and Scandinavian groups each of three harmonised Governmental registration arrangements, every country still has its own specific type of registration information and data. Each national scheme is of course regarded as impeccable: and yet they are all tediously and expensively different, and at times widely different. One hopes that a real and viable beginning can be made within EEC in the next few years, for which everyone would eventually be thankful, because logic and common sense could spread usefully from such a nucleus. We look to Brussels, and its expected removal of barriers to trade.

TRYING OUT NEW RULES

Almost all Governments now have obligatory legislation, often extremely meticulous and inclusive, controlling the introduction and sales of pesticides. In most countries, new rules and regulations are frequent. Although we in this country are well aware that neither the basic principles of our cricket nor our voluntary notification scheme are fully comprehensible to other countries, the industry would welcome some period of hesitation and consultation by any Government, as in UK, before finalising its new ideas and requirements as legal obligations. A period of voluntary try-out, permitting adjustment before finalisation, has everything to commend it and nothing except old-fashioned distrust to condemn it.

FORWARD PREDICTION OF NEW PROBLEMS

Agricultural policies in the various and changing comities of nations seem always to be under the inflence of some dire crisis, and indeed agricultural development plans and programmes seem to be rather more clear in the developing countries than in the sophisticated ones. The pesticide industry would be helped by firm official indications of future cropping and commodity plans from individual Governments, and preferably from supra-Governmental authorities, such as EEC or FAO. The lag period between aiming at a new crop's weed or pests targets and hitting them commercially is so long that careful prediction of future intentions in agriculture could much affect and improve R. and D. programmes in the ensuing ten years.

TRIALS DATA

Applied Biologists in the pesticide industry, accustomed to thinking in terms of scores, hundreds or even thousands of replicated plot trials over many countries in a product-proving period, have never been able to understand how some countries rely on a few miniature trials carried out by official research stations to decide on whether a product is up to local standards or not. This is an archaic system, fortunately now not widespread, but still lingering on in otherwise highly scientific communities. The industry could be much helped by introduction of a system whereby all its performance data were submitted to some independent international authority, so that a collective and perhaps computerised assessment of a new product's performance and variability was available and then taken into much account by all countries, as it would be by the firm itself. The official mini-trial arrangements are reminiscent of one of my erstwhile chemical colleagues who quoted a metabolite's LD50 from one test on just one mouse - explaining that "it was of course a very standard mouse, and half-dead!"

LIMITED EARLY SALES PERMITS

Another measure which would help industry to overcome its development cost and investment-decision problems would be universal use of the restricted acreage sales permit, or the temporary permit introductory arrangement, as already practised by some countries, but not all. The commercial introduction of a new product increasingly demands information not merely on technical performance in the hands of experimentalists in industry, but also on how it behaves when paid for and used by growers themselves in their own machinery, with all the minor errors in timing, dosages and application which are bound to occur in field use, and which may affect the value of the product and therefore its potential as a manufacturing investment. Every Government could safely permit and indeed encourage limited and controlled acreage sales on the basis of preliminary evidence on safety in use and potential value to agricultural practices and productivity, for one, two or three years.

MINORITY PRODUCTS

Another area where Governmental tidying up seems overdue is in the once-and-for-all consolidation of regulatory procedures in any country to cover all uses of all pesticides. Even in this by no means backward country, where for many years all has been crystal clear for agricultural and horticultural uses of chemicals, there are different and at times rather confusing procedures for industrial uses, veterinary uses, or public health uses. In most instances, these are the result of historical Departmental responsibilities or occasionally feuds. It really is time that some official procedures were streamlined in the interests of progress and of tax-payers. Perhaps industry should next develop a confusion-eradicant, or a simplicity-promoter, or even a bovicide for the control of the occasional sacred cow which turns up at official meetings. Such a product would also be of frequent value in industry, I hasten to say.

INTERNATIONAL BODIES NEEDED

One of the increasingly necessary provisions for the future seems to be efficient and respected international authorities, either associations or committees or agencies, by which the industry and Governments can resolve matters satisfactorily before - or after - they have become tangled in competitive national issues. The industry has for several years had its GIFAP, which can probably be made into anything that the future situation demands, as long as the major companies give it their support. We already have two official international agencies in WHO and FAO, who between them could increasingly act as catalyst or lubricant for situations where progress was hindered by lack of national coordination. All such matters cost money: but at present a lot of money is already being spent because of lack of coordination of views, or the absence of multi-national systems for official controls. There have been some minor adventures in attempted coordination, but as yet we are dealing with the periphery of the problem, not the hard centre. We have also seen and still have some top-heavy international Committees, of course, which should not be taken as examples of what is best for swift and proper progress.

PRIORITIES FOR RESEARCH WORKERS

There are many other problems where we can jointly make progress by industry-official collaboration in the future. On the purely scientific side, it is a matter of some anxiety that new and exciting areas of chemistry or applied biology for use in pest control operations are few and far between. There is scope for periodic discussions and decisions between Universities, official research bodies and industry on priorities in pesticide research, where each should think hard on what it can do best and most efficiently, and equally on what it should not try to do because others can do it better. When such matters are discussed, we should increasingly bring in the economists, because competing research projects are very susceptible to cost-benefit comparisons. The resources needed for the different tasks of ensuring future success are very different, and no organisation has the lot in full measure.

SAFETY

There is one specific area where pesticides have further progress to make, and that is in even higher standards of safety in packaging, transport, handling and spraying. One of the latest Technical Reports from WHO estimated or more truthfully guesstimated that there may be half a million cases of pesticide intoxication in the World every year, which if true is not exactly a tribute to industry, Government or individual humans. Even if the figure is in error by a factor of two, or four, or ten, or a hundred, it is still worthy of our thought. My own thoughts are quite simply that we should all put still more consideration and action into safer chemicals, safer formulations, packages, seals and closures, more striking and intelligible labels, more education aimed at young people in schools and agriculture, better aids to measuring, simpler standards of personal protection and more appropriate availability of chemicals according to their degree of hazard to the user population. It seems probable that if all the money spent unnecessarily on proving that minute pesticide residues in food were not teratogenic, nor mutagenic, nor carcinogenic were ascribed for the next ten years to safety measures of more practical nature, we could make some laudable advances in human well being, and save many lives.

Several countries' Trade Associations have already adopted agreed codes of practice on matters which may involve users, the public or Governments, and occasionally, these are utilised when some deficiency or errant act has occurred. I myself have long thought that Trade Associations should show rather more direct interest when something has gone wrong, and conduct some form of internal enquiry when an event or series of events have prejudiced the interests of other members, or appear to infringe the code of practice. Such internal enquiry could well help to prevent further incidents. Information on any such incident is usually available in some part of a company's organisation, as a normal part of the information coming from sales or technical service visits or reports. We all know that such corporate enquiries can be a good method of preventing future misdemeanours.

THE ENVIRONMENT

In recent years there has been a helpful and timely decrease in the protests made by the public on the side-effects of pesticides, although there is a continuing minor apprehension and criticism. The recent spate of more general protest about the 'environment' has not hit pesticides very hard, so one may conclude that the industry has absorbed a series of lessons of the past, and nowadays automatically takes useful steps to avoid causing or permitting manifest side effects. Public relations on pesticides are not therefore a serious problem at the present time, but any really major incident in the future could easily flare up lobbies of criticism. From memory of the past, prevention is clearly better than cure, and the joint operation of Government and Industry to prevent any such future problems seem the best way to operate. The most sensitive area for the future appears to be potential contamination of rivers and estuaries, by either local manufacture or intensive use of biologically active materials such as pesticides. It is an axiom of occupational health that safety always has to be bought, and this has to be extended to matters of environmental cleanliness. The prevention of significant environmental contamination by pesticides therefore seems to narrow down to the allocation of cash to prevent discharge of active manufacturing or formulation wastes, and to studies on the movement of active materials from soils into water, especially where a product is aimed at extensively-grown crops.

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THE ROLES OF A GOVERNMENT APPROVAL ORGANISATION AND INDEPENDENT ADVISERS IN THE EFFICIENT USE OF PESTICIDES

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Summary Views are expressed on the standards of pesticide efficiency of new and established products. Ways and means by which these standards can be maintained include independent monitoring and the withdrawal of approval of outmoded uses or products. Standardisation of methods for biological evaluation in Europe should also help to raise standards and enable comparisons of similar countries' data. Crop safety, including varietal reactions, taint testing of pesticides used on processed crops and trials coverage under UK range of crop conditions are other important aspects to be considered. The need for an evaluation of the problem of minor uses is stressed so that a co-ordinated plan can be formulated for obtaining their clearance and approval. Proposals are made for raising the status of the "Insecticide and Fungicide Handbook" to compare with the authority of the "Weed Control Handbook". The need for the sharing of uses approved for non-patented products by firms is advocated to avoid confusing the adviser and grower. Concern is expressed over the efficiency of alternatives to the organochlorine insecticides which could be allayed by improving the advice to growers on their use. A warning is given of any hasty withdrawal of the organomercury seed dressings until a range of adequate replacements are found. In spite of these problems, continuance of the close collaboration between government, independent research and industry should overcome most of them.

INTRODUCTION

I must stress at the outset that the views expressed in this paper are my own and should not be taken as having any official government support. The title also suggests that I have attempted to cover the roles of "others" as well as that of my own organisation. This is correct only up to a point as it has not been possible to consult with representatives of all the independent advisory services mentioned here. These include my advisory colleagues in government service, local government authorities, food processing firms and crop commodity organisations. I must therefore offer my apologies to them if their roles have not been adequately represented.

Although I have mainly concentrated on the United Kingdom situation, many of the problems discussed are common to other countries. As a consequence of our entry into the European Economic Community it is particularly important that the standards of pesticide efficiency we adopt in the UK compare favourably with those of our fellow members of EEC.

The "efficient use of pesticides" is a very wide subject. I can therefore only choose some of the major aspects and will begin with the most difficult, controversial and often indefinable one namely standards of efficiency.

ESTABLISHING STANDARDS

The setting and maintaining of standards of efficiency is probably our major role in pesticide development and use. The most difficult part of this role is reaching an acceptable standard which is:

(a) worthy of the Government's Approval mark

(b) carries the confidence of the independent adviser

(c) bears the full commercial backing of the pesticide firm, which after all can be held responsible if these standards are not fulfilled.

I must explain that beyond certain minimum requirements there are no predetermined criteria laid down by the UK Approval Scheme. Each application for approval is treated on its merits and an assessment is made of the data supplied by the firm, that which is available in authoritative publications or received direct from independent sources. The quality and quantity of data submitted by firms can be extremely variable as a result of the interplay of many factors too numerous to mention and not easy to resolve. However, standards of efficiency are set as high as possible and a new product seeking approval must be tested to the same standard as other approved products and must perform as consistently as an acceptable standard.

Ideally a product should only be approved and recommended by advisers if it is as good as the best one already approved for that purpose. But there are many other factors which influence this situation, eg cost of treatment, safety aspects, behaviour under different crop conditions, pest and disease resistance and above all, definition of "best", so that a compromise must be reached in the setting of standards of efficiency.

The major test comes when there are no previous chemical methods available for the control of a particular pest or disease. In such cases the test must be whether the product can be shown to give a consistent benefit to the user.

I must emphasise that before decisions on approval are taken by the officers of the UK Approval Scheme, consultation has usually taken place with experienced independent advisers and research workers so that every effort is made to obtain a balanced view of the product label claims. However there may be no additional data over and above that provided by firms or if there are, these may be of a kind that is not of direct application. Firms are therefore encouraged from the early development stage to obtain as much independent evaluation of their products as possible. In spite of our efforts in this direction, the insularity of some firms and the sometimes limited sources available for independent evaluation make this a major problem so that approval has to depend too often on firms' data alone. Where the data is incomplete the Scheme is weakened if a firm continues to market without approval. This is further aggravated should the independent adviser recommend these non-approved products where there are satisfactory approved alternatives.

Whatever final decisions are taken on approval it is important fully to appreciate what is actually claimed for the product. This can be "complete control" of the pest or disease, or only "supression", "reduction", etc together with other qualifications on its performance. This does not imply a lowering of standards of efficiency but a clear and honest statement of what that product is expected to achieve.

MAINTAINING STANDARDS

As well as the setting of standards for new products we must not forget the problem of maintaining these standards during their use. At present there is little if any follow-up subsequent to the granting of approval. Only specific cases of complaint are investigated and these only superficially. The performance of newly-approved products should be monitored for at least two seasons post-approval after which they should be reviewed say, every five years. Another approach might be provisional approval at first followed by full approval after say two years commercial usage backed by scientific assessment.

The efficiency of long-established products needs also to be kept constantly under review so that when they become outmoded, approval can justifiably be down-graded or withdrawn. To some extent the shortcomings of products are being found out but mainly from other sources than the firms themselves. A few examples given in Table 1 of where action by my organisation has been taken over the past few years illustrates what can be done on these lines.

Table 1

Examples of "disapproval"

Action	Chemical	Pest/Disease	Crop
Product withdrawl	Ziram	Scab	Apple, pear
Use withdrawal	Thiram	Scab	Apple
Use withdrawal	Lead arsenate	Codling, tortrix	Apple, pear
Resistance warnings	Benomyl	Grey mould	Various
	Organophosphorus	Red spider mites	Various
	Mercury seed dressing	Leaf spot	Oats

These are only a modest contribution to the maintenance of standards of efficiency. A further critical examination of the long list of approved products (Anon 1973) is needed if we are to be spared the criticism of carrying too many outmoded products or uses.

INSECTICIDE AND FUNGICIDE HANDBOOK

I would like to suggest that the British Crop Protection Council could also help in this direction by raising the status of its publication "The Insecticide and Fungicide Handbook" (Martin, H. 1972) to the authoritative standing of its corresponding "Weed Control Handbook" (Fryer, J. and Makepeace, R. 1972). The latter publication contains recommendations that are based on proven efficiency agreed through an expert committee procedure. If such a system were adopted in the preparation of the "Insecticide and Fungicide Handbook" recommendations could be carefully scrutinised and only those which had been proven scientifically would be retained.

In advocating this approach I am not decrying the difficult task that the editor has carried out in the past and the useful work done by his contributors which include myself. What I would like to see is a reference work matching the standing and respect of its sister publication the "Weed Control Handbook".

METHODS FOR BIOLOGICAL EVALUATION

Another aid to improving pesticide efficiency is via the standardisation of methods for their biological evaluation. Many countries already have their own methods and my predecessor, the late Dr E A Riley, with the help of independent advisers and research workers produced a document as far back as 1962 giving some guidance on the type and extent of data required for field trials on products submitted for approval in the UK.

A new impetus has recently been given to harmonisation by the European and Mediterranean Plant Protection Organisation (EPPO) which is attempting to establish a model for the biological evaluation of pesticides and individual methods for specific pests and diseases. So far progress has been achieved in the standardisation of methods for the pests and diseases listed in Tables 2 and 3.

Table 2

Proposed EPPO methods for biological evaluation - Insecticides, etc.

Pest	Crop	Country responsible
Cabbage root fly	Cauliflower	United Kingdom
Carrot fly	Carrot	Netherlands
Codling moth	Apple	France
Colorado beetle	Potato	USSR
Red spider mite	Apple	Switzerland
Onion fly	Onion	Federal Germany
Rodents	Various	Finland

Table 3

Proposed EPPO methods for biological evaluation - Fungicides

Disease	Crop	Country responsible
Blight	Potato	USSR
Grey mould	Strawberry	Italy
Grey mould	Vine	Portugal
Leaf spot	Beets	Federal Germany
Powdery mildew	Apple	United Kingdom
Powdery mildew	Vine	France
Scab	Apple, pear	United Kingdom
Seed-borne	Cereals	Finland

If agreement can be reached on these methods it should be possible to up-date our own and compare efficiency data from other countries with similar growing conditions. However most countries, including the UK, will still require biological evaluation to be undertaken predominantly under their own set of conditions.

INDEPENDENT EVALUATION

The UK Approval Organisation as set up at present consists of only three scientific officers who have to make the final decisions on the approval of Insecticides, Fungicides and Herbicides respectively. The organisation is neither staffed nor equipped to carry out any field testing or follow-up work and can only inspect a sample of the firms' own trials. Independent research stations and advisers have no obligation to carry out work in support of the Approval Scheme but fortunately their work can sometimes provide unbiased data against which a firm's claims can be judged. In some cases firms rely heavily on the expertise of independent workers, and in general there is a great need for increased independent evaluation of pesticide performance. If we are to demand more evaluation then drastic changes in the present financing arrangements of the UK Approval Scheme would be necessary to allow for the increased staffing and resources that would be required to alter this situation. Perhaps the Scheme could then finance some of this independent monitoring on a contract basis with existing independent research and advisory bodies.

CROP SAFETY

This is a paramount requirement for all pesticides including coverage of as wide a range of commercial varieties as possible. If there are any untoward effects on the crop these limitations must be clearly pointed out on the product label. Testing on a wide range of varieties can be a problem, especially in the early life of a product. The advent of new varieties and the ever-changing pattern in their popularity can cause problems with any product. Guidance is sought from as many authoritative sources as possible on the choice of varieties to be tested for phytotoxicity. More often than not the safest approach is to require the product label to state what varieties can be safely treated and what cannot.

SIDE EFFECTS

Only one example can be taken and this has to be taint. Food-processing firms are particularly concerned about the risks of pesticides causing taints or off-flavours in crops. With the co-operation of the many interested parties and through the guidance of the Advisory Committee on Taint of the Ministry of Agriculture, Fisheries and Food a satisfactory system has been developed for taint testing (Arthey, V. D. et al, 1958). Most of the tests are carried out by the Fruit and Vegetable Preservation Research Association supplemented by the testing of jams by the British Food Manufacturing Industries Research Association. Some of the processing firms also carry out their own tests. The UK Approval Organisation takes into account the results of these tests when approving label recommendations and endeavours to safeguard the interests of growers and processors in this respect. Warning clauses are required on the product label until satisfactory results have shown that there is no risk of taint or where it has been proved that there is a risk.

There is room for improvement in these taint testing arrangements as some pesticide firms consider the requirements too demanding and some of the processors claim that they are not adequate. It would seem that better collaboration and more formal agreement between all parties concerned is needed.

GEOGRAPHICAL COVERAGE

Pesticides should be tested over as wide a range of climatic, soil, growing conditions and cultural practices as are relevant to the crop and pest or disease concerned. Unfortunately the lack of resources of some firms, reluctance to seek independent help, together with other priorities of experimental and research stations prevents the full coverage of the United Kingdom that is so desirable. One of our roles should therefore be to improve this situation. The Approval Organisation also has liaison officers in Scotland, Northern Ireland, Guernsey, Jersey and the Isle of Man, who are prepared to help on regional problems and to stimulate the interest of their advisers and research workers in the performance of pesticides under local conditions.

MINOR USES

A major problem confronting the development and use of pesticides is the safety clearance and approval of pesticides for so-called minor uses. This is mainly due to the lack of profit incentive for firms to obtain official clearance and approval because of the small usage of their products for these purposes. It is particularly the case for products based on chemicals that are out of patent.

What is needed is an evaluation by all the interested parties of the current data available and a co-ordinated plan for initiating any research that may be necessary to fill the gaps. A start has already been made to examine this problem in the UK and discussions begun between representatives of the pesticide industry and Government. The problem must exist in other countries and for some years the United States of America have had a project called the "Clearance of Pesticides as a Public Service" (Starnes, O. 1964) which may afford useful ideas on procedure.

SHARED USES OF "OFF-PATENT" PESTICIDES

Another topic which causes problems to my organisation and the independent adviser are uses of a non-patented pesticide which are not approved for all products with the same active ingredient. This can be best illustrated by considering a specific chemical eg. fenitrothion in Table 4.

Table 4

Fenitrothion

Approved Crop Uses
Control of aphids, apple blossom weevil, apple sawfly, capsids, codling, tortrix and winter moths and suckers (apple and pear), aphids, caterpillars and sawfly (plum), capsids and sawflies (blackcurrant and gooseberry), raspberry beetle, strawberry tortrix, aphids, midge, moth, thrips and weevils (pea), saddle gall midge and (by making a bran bait) leatherjackets in cereals.

Approved Products	
Accothion	Dicofen
Agrothion 50	Fenstan EC 50
Boots Fenitrothion Insecticide	Folithion
Ciba-Geigy Fenitrothion 50 EC	Shell Verthion

Of the 8 products listed not one carries all of the approved uses. A summary of the numbers of uses for each product is shown in Table 5.

Table 5

Incomplete crop pest coverage
by fenitrothion products

Approved Products 8	24 Approved Uses
A	23
B	22
C	20
D	19
E-H	18

Thus the grower who follows independent advice to use this chemical cannot be certain what uses will be found on the product label. This is because some of these uses were based entirely on development work carried out by some of the firms, whereas the evidence for the majority of the uses came from independent sources. Also this situation discourages some firms to seek approval if they cannot obtain all the approved uses.

A solution to this confused situation would be a sharing of these special uses by all firms and avoidance of this situation in the future by industry sharing the costs of development amongst its interested firms.

This problem applies to many other chemicals that have been long off patent and will be an increasing one as more proven chemicals reach this state.

ALTERNATIVES TO ORGANOCHLORINES

At the 6th British Insecticide and Fungicide Conference (Gair, R. 1971), a warning was sounded about the gaps left in pest control by the restrictions placed on the uses of some of the organochlorine insecticides. Further limitations have arisen with the withdrawal of the aldrin and dieldrin seed dressings for use on cereals and, apparently for commercial reasons, the removal of the dieldrin/thiram seed dressing from the UK market. There are already adequate replacements for the insecticidal cereal seed dressings but there are as yet no approved alternatives for the control of onion fly and bean seed fly which was the function of the dieldrin/thiram product. Suitable alternatives may not be far away but they could require similar precision in application as some of the enforced replacements for DDT for pea midge control. The shortcomings of some of these alternatives, which are less persistent, can usually be overcome and give better control than their predecessors when applied at the optimum time. This requires much better guidance on when to spray, which is perhaps where our greatest contribution can be made.

As we have heard at this Conference the search is in progress for alternatives to the organomercury seed dressings where one of the major problems is to match the very high standards of these long established products. The dangers of too hasty withdrawal of such highly efficient products before there has been enough experience of a range of alternatives should be given serious consideration by all concerned.

CONCLUSIONS

I have attempted to highlight the problems facing the development and use of pesticides as they impinge upon an official approval organisation and the independent adviser who is, or should be, in closest touch with the grower. I may have appeared to be pessimistic but I believe that the continued collaboration of Government and the Pesticides Industry together with support from the independent research and advisory services will result in a solution of many of the problems that I have touched on.

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OPPORTUNITIES FOR COLLABORATIVE RESEARCH AND DEVELOPMENT BETWEEN INDUSTRY AND OFFICIAL ORGANISATIONS AND UNIVERSITIES

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Summary The development of new pesticides has become more costly due largely to more stringent requirements for safe use in terms of mammalian toxicity, hazards to wildlife and contamination of the environment. Safety testing is the responsibility of the manufacturer but official research organisations and university departments do collaborate in the evaluation of new compounds for biological efficiency. The scheme for evaluating new compounds in the U.S. Department of Agriculture is described and compared with the informal arrangements that exist in the United Kingdom. Suggestions are made as to how these arrangements might be strengthened so that official research organisations can examine a wider range of compounds before they are released commercially and so can contribute to their more rapid commercial development. It is suggested that the BCPC might provide advice on ways of improving collaboration between research institutes and industry to the Research Boards of the newly constituted Joint Consultative Organisation of the ARC, MAFF and DAFS.

There is a continuing need to develop alternative or better pesticides for agriculture to increase productivity and to improve quality, and this has to be done against a background of technical, economic and political constraints. It will be the purpose of this paper to examine the role that research institutes and university departments can play to assist in this development working closely with pesticide manufacturers.

During the past ten years the development of new pesticides has become more costly for a variety of reasons. The most obvious of these is the higher costs involved in the extensive toxicological testing required to get safety clearance throughout the World. These requirements are such that no firm will contemplate releasing a new pesticide until it is assured of a major outlet. The consequence of this is that smaller, more specialised outlets can only be catered for if the new chemical has a primary use in a crop or crops of major importance. Such a situation militates against the development of more specific compounds since they will tend to have a limited spectrum of activity. When one considers that such compounds are also more likely to induce resistance or tolerance in pests and pathogens the overall prospects are not good.

Responsibility for toxicological testing continues to rest with the manufacturer and he has to carry the cost. Official research establishments are not involved in such testing other than on a limited scale in the MRC Unit of Toxicology. In testing for hazards to wildlife the requirements of the Pesticides Safety Precautions Scheme have also, in the main, to be met by testing done by manufacturers.

There have, however, been instances of collaboration between industry and official research establishments both in the assessment of hazards to wildlife and in the evaluation of the usefulness of pesticides in nature conservation. An example of the latter was a series of collaborative trials of the use of the bipyridyl herbicides as aquatic herbicides undertaken jointly by the Monks Wood Experiment Station of the Nature Conservancy and the Ecology Section of Jealott's Hill Research Station of Plant Protection Ltd. Most official research on pesticide toxicity to wildlife has of course been independent of the interests of industry, and there have been cases where pesticide manufacturers have felt that the efforts of the official research organisations were not being exercised with quite the objective approach and interpretation that the situation demanded. Clearly, effects on wildlife and on the environment generally are matters of great public concern and ought to attract a greater measure of collaborative research. It is after all in the interests of both the manufacturer and the official research worker that farmers should be provided with effective crop protection chemicals that will not have adverse and persistent biological effects in the environment.

The major opportunities for collaborative work, however, arise in the evaluation of the efficiency of new compounds as pesticides. This does not mean preliminary screening but rather the later stages of evaluation where useful activity has already been established by the manufacturer and where the research institute may be able to undertake more specialised evaluation. In this connection there are certain points of principle that need to be recognised. As I explained in a paper at the Stirling Conference of the Society of Chemical Industry in 1969 (Rudd-Jones 1970), the Agricultural Research Council has always considered that the discovery and development of new pesticides is properly left in the main to commercial firms which have far greater resources for this type of work.

In a few instances individual scientists who have a flair for more rational synthesis of novel biological activity have been encouraged to pursue such studies. An example of this type of research was the development of the synthetic pyrethrins which were first made at Rothamstead Experimental Station (Elliott, M. 1967). Where patent protection of such developments can be established there is a requirement that this should be done through the National Research Development Corporation. (NRDC).

By contrast the university research worker is able to operate in a more independent manner. Unlike the research institute, a university department is not supported exclusively by the taxpayer to undertake research in the interests of the food and agricultural industries, but rather to engage in education at the undergraduate and postgraduate level. This means that universities can and do receive grants from individual firms which may cover the cost of primary evaluation or development of new chemicals with the results of such research being made available to such firms under confidential cover. There is also a scheme administered by the Science Research Council known as CASE (Co-operative Awards in Science and Engineering) whereby individual firms make grants to university departments which are then matched by a similar or larger contribution from the SRC. It is true that such awards can now be made to research establishments, but in this case the research institute is the industrial partner. For reasons that are difficult to comprehend these grants come through the SRC, and neither the ARC nor the Ministry of Agriculture are consulted about their merits. Because the university professor is able to act as a freer agent than the director of a research institute, he may be a more attractive proposition to the pesticide manufacturer who is seeking some co-operative arrangement. Whilst this is understandable it is unfortunate because the research institute will normally be in a stronger position professionally both with regard to facilities and staff. Furthermore in a university department there is no continuity of staffing and most of the research has to be done by young graduates working for higher degrees on temporary appointments.

It is my view that links between manufacturers and research institutes ought to be strengthened beyond the purely informal and personal arrangements that exist at the present time. Wilst I would not wish to see the agreements made too formal and rigid, I think we would do well to examine the scheme which is operated by the United States Department of Agriculture and to consider how far this might be modified to suit our needs. The USDA operate an arrangement whereby manufacturers can submit new pesticides in the course of development for evaluation at research institutes in the Agricultural Research Service. Table 1 summarizes the kind of information that has to be provided before a chemical can be tested.

Table 1

Particulars of new pesticides submitted to the
U.S. Department of Agriculture for research evaluation

1. Chemical Name
2. Type of test - fungicide, herbicide, insecticide, nematicide
3. Patent status - granted, applied for, contemplated
4. Empirical Formula
5. Molecular Weight
6. Structural Formula
7. Physical Properties of Active Ingredient - melting point, boiling point, density, purity, etc.
8. Stability
9. Solubility
10. Formulation
11. Active Ingredient
12. Type of Action - contact, systemic, other
13. Mammalian Toxicity - LD_{50} (specify animal and method)
14. Toxicity assessment - extremely hazardous, hazardous, considered hazardous, relatively safe
15. Precautions necessary for safe evaluation - first aid
16. Inert Ingredients
17. Suggested Use, Rate and Method of Application

The procedure is that chemicals for evaluation are recorded centrally and given an Accession Number. They may then be despatched to a number of USDA Laboratories for evaluation. The period of confidentiality is normally set at 12 months but there is provision for this period to be extended for up to a further 12 months.

Looking at this list of requirements in a British context, I think the first point to note is the apparent readiness of American manufacturers to release chemicals through the scheme before they have adequate patent protection to safeguard a new compound from accidental or deliberate disclosure to a competitor. It may be of course that in practice this does not happen. However, the impression given by British manufacturers is that they would want to have registered a provisional patent before agreeing to it being examined by a research institute. Certainly the majority of directors of research institutes would be most reluctant to accept the responsibility of evaluating a new compound without patent protection.

Turning to the other requirements, no director would be prepared to evaluate a chemical unless he were given its structural formula and the details of its formulation, as well as adequate data on mammalian toxicity to ensure that his staff were not exposed to any undue risk in working with the compound. The director would need to satisfy himself too that the preliminary information about the new compound was sufficiently promising and relevant to his own programme of research to justify more detailed evaluation within his institute.

As far as confidentiality is concerned, a delay of 12 months should be acceptable under normal conditions although there may be objections to its extension beyond two years. Similar delays would in any case operate where a chemical was being developed by a research institute or university department through NRDC. The director has always to remember that the institute is financed by the taxpayer and that the research undertaken must not unduly favour a particular firm. This means that the early publication of results is important, not only to justify the allocation of funds for research, but also to promote the career interests of members of staff within the agricultural research service.

Different criteria may operate within university departments. In many instances the research on new compounds will be undertaken by postgraduate students who are proceeding to a higher degree. To satisfy the requirements for the higher degree a thesis must be prepared although the contents do not have to be published within the same timescale. Since research directed towards a higher degree may be considered to have an educational component, and since it is not supported so directly by the taxpayer, the need to publish in order to justify the expenditure of funds is not of paramount importance.

If we consider the type of chemicals that might become available from manufacturers they will normally fall into two classes.

Table 2

Types of collaborative investigation of crop protection chemicals by Research Institutes, Universities, and Industry

1. The evaluation of specific compounds; such compounds can be divided into two groups -

   (i) compounds on which the manufacturer has decided to proceed for a primary use but which may be of some secondary interest and application in other sectors of agriculture or horticulture;

   (ii) compounds which have shown some interesting physiological, fungicidal or pesticidal activity in screening programmes but on which the manufacturer has not yet made a formal decision about further development.

2. Basic studies concerned with establishing general principles relating to particular types of activity.

In both classes of chemicals there are opportunities for scientists in research institutes to undertake work. In the first class, these are concerned with additional uses secondary to the declared intent of the Company to market a product for primary use on a major crop or crops. Within the special requirements of protected cropping under glass there are a number of examples that might be cited because no manufacturer has so far as I am aware looked upon the glasshouse sector as a prime consumer of pesticide chemicals.

The majority of compounds in the second class are unlikely to be developed for commercial use. Nevertheless there may be a number of them with interesting and novel activity that could yield information that might lead to the more rational synthesis of new compounds with commercial potential. The examination of such compounds by scientists at research institutes who can take a longer term view than their colleagues in industry might contribute to commercial development.

There is a further area of research in which the major companies are engaged and where collaboration with official research workers might yield benefits. This area can be described as one of basic studies concerned with establishing general principles relating to particular types of activity. These would include studies on uptake, distribution and metabolism, including mode of action, in plants and soils. This would also cover problems of usage such as the development of resistance or tolerance to specific compounds in pests or pathogens, phytotoxicity as well as compatibility and specificity in integrated control programmes.

I should like to consider a few examples where there might be benefits from closer collaboration in research. The first concerns the need for more determined efforts to find alternatives to the organo chlorine insecticides and the organo mercurial fungicides. The situation in the USA with the current ban on DDT is becoming increasingly difficult, especially in forestry and for the control of the beetle vector of Dutch Elm disease in amenity planting of elms.

More specific examples are to be found in the glasshouse sector. If we consider the control of cucumber powdery mildew (*Sphaerotheca fuliginea*) in an integrated control programme involving the use of biological control agents, two fungicides are available - benomyl and dimethirimol. Strains of the fungus tolerant to one or other of these compounds have appeared in commercial crops, and in a paper given earlier in this conference by my colleagues, Miss Ebben and Dr. Spencer (Ebben & Spencer 1973), they have shown that it is possible to maintain control of the disease where tolerant strains are present by applying the two fungicides alternately, depending on the tolerance of the primary infection, or together. So far no strain tolerant to both compounds has appeared, but clearly this is a situation that ought to be anticipated by collaborative research. Indeed, ethirimol, an analogue of dimethirimol effective against cereal powdery mildew, has been withdrawn as a seed dressing for winter sown barley in the current season because of the appearance of a tolerant strain of mildew. The manufacturers have taken a highly responsible decision to withdraw it presumably because they consider that the compound is likely to continue to be effective in the control of mildew on spring sown crops if the fungus on winter sown crops is not subjected to extended selective pressure.

Programmes of integrated control involving both biological and chemical agents demand a detailed understanding of the compatibility and specificity of particular pesticides. In another paper given earlier at the conference by my colleagues, Dr. Scopes and Miss Biggerstaff (Scopes & Biggerstaff 1973), an account was given of the development of an integrated pest control programme for year-round chrysanthemum production. This depends on the use of a dioxathion/pirimicarb spray at two-weekly intervals to control leaf miner, which at present is not susceptible of biological control. Fortunately this combined spray gives effective control without causing damage to the predators or parasites used to control the other pests. This was not true of some of the other compounds examined, such as trichlorphon, which, although effective in controlling leaf miner, appeared to exert a fumigant effect in killing predators which resulted in outbreaks of spider mite.

In these studies we have been able to work very closely with pesticide manufacturers, but I use them as examples to illustrate the need for a greater measure of co-ordination of research and development between official organisations and industry. As I have said, the arrangements in the past and at present are based on personal contacts between individuals, and they have much to commend them because they are based on mutual confidence and professional understanding. I am concerned, however, that at a time when there are pressures to improve the safety of pesticides and to eliminate their persistent effects in the environment on the one hand, and pressures to increase yield and improve quality of crops on the other, collaboration and co-ordination should be promoted through more formal machinery. As Dr. Gerwitz of Monsanto (Europe) said at the recent Society of Chemical Industry Conference in Stirling (Gerwitz, in press): "Successful introduction of new products to meet agricultural needs must involve co-operative effort between both the public and private sectors. Key elements in this effort include extensive exchange of information, the existence of world-wide testing centers for field evaluation, and a rational approach to the establishment of a product's safety".

The reorganisation of official research and development in agriculture that is now taking place in this country ought to provide a forum in which discussions on collaboration can take place. An examination of the structure of the Joint Consultative Organisation of the ARC, MAFF and DAFS that has been set up and of its constituent Boards and Committees suggests that opportunities for such collaboration will be considered. However, I feel that there would be merit in the British Crop Protection Council taking the initiative in setting up its own working party to examine the possibilities of collaboration so that the Council can advise the appropriate Research Boards.

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CEREAL SEED TREATMENTS : PROBLEMS AND PROGRESS

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Summary The problems associated with treating cereal seed against soil pests, soil and seed borne diseases and foliar diseases are discussed in relation to the biological requirements and the properties of the chemicals used in each case. Traditional commercial methods of applying powder treatments are unsatisfactory because adhesion is poor and loadings are usually well below the target. With liquid treatments, average loadings are nearer the target but the distribution between individual seeds is very uneven. New formulations and methods of application are being developed to overcome these problems, but excessive adhesion could decrease effectiveness, particularly for chemicals which act mainly in the soil, and uniform distribution could increase phytotoxicity in some cases.

Résumé Les problèmes relatifs au traitement des graines de céréales contre les organismes nuisibles dans le sol, contre les maladies transmises par les semences et par l'intermédiaire du sol, et contre les maladies foliaires, sont examinés par rapport aux exigences biologiques et aux propriétés des substances chimiques utilisées dan chaque cas. Les méthodes commerciales traditionnelles qui consistent à appliquer des traitements en poudre se révèlent peu satisfaisantes en raison d'une adhérence défectueuse et de charges généralement bien inférieures à celles que l'on se propose d'atteindre. Avec les préparations liquides, les charges moyennes se rapprochent du but proposé, mais la distribution sur les différentes graines est très irregulière. Des formulations et des méthodes d'application nouvelles sont en cours de développement pour résoudre ces problèmes, mais une adhérence excessive pourrait réduire l'efficacité, particulièrement dans le cas des substances chimiques qui agissent principalement dans le sol, alors qu'une distribution uniforme pourrait, dans certains cas, accroître la phytotoxicité.

INTRODUCTION

Seed treatment has been accepted for many years as a convenient, economical and efficient method for applying suitable insecticides and fungicides to cereals. In considering the deficiencies in seed treatments which have been revealed by recent investigations it is important not to lose sight of the considerable advantages which the method offers. The successful control of many seed and soil borne diseases by organomercury fungicides which can increase yields by up to 30% and improve seedling emergence and establishment by as much as 70% (Dillon Weston et al, 1937) is now taken for granted. Insecticidal seed treatments are somewhat more recent but are now also well established. It is over 20 years since Jameson et al (1947) described the development of seed treatments to control wireworms, and their use against wheat bulb fly larvae followed shortly afterwards (Gough and Woods, 1954). Potter et al,(1956) showed that treating seeds with BHC gave increases in yield comparable with those obtained when approximately three times as much chemical was drilled with the seed or up to eight times as much was broadcast before sowing. Treatment of seeds with systemic fungicides to give extended control of powdery mildew is a much more recent development where again it has been found that the chemical is utilised much more efficiently than with less localised applications such as drilling with the seed or broadcasting (Brooks, 1970).

However, although the usefulness of seed treatments has been clearly established, experience in practice has also emphasised that, as applied and used at present, they have several disadvantages and limitations. In particular, recent studies have shown that many commercial methods for applying seed dressings are unsatisfactory. In this paper, the problems associated with seed treatments against soil pests, soil and seed borne diseases and foliar diseases will be considered in relation to the biological requirements and the properties of the chemicals used in each case. Some possible improvements will be discussed.

INSECTICIDAL SEED TREATMENTS

In Britain, the main use of insecticidal seed treatments on cereals is for protection against wireworms, although damage by wireworms has become less important as the amounts of old grassland ploughed for arable use have decreased. Much winter wheat is also treated at higher rates against wheat bulb fly and I shall concentrate on control of this pest here. In general, insecticidal seed treatments have been reasonably successful, but results in practice have been variable and control has sometimes been unsatisfactory. To seek explanations for this unreliable performance, the fate of the chemical after application was studied in a series of investigations at Rothamsted Experimental Station, the MAFF Plant Pathology Laboratory and by the Agricultural Development and Advisory Service (ADAS). Some of the studies were previously reviewed by Lord et al (1971a).

The reasons for variations in performance on different soils were first investigated by analysing soils and plants from different sites where treated seed was grown. During these investigations it was discovered that the amounts of insecticide on individual seeds prior to sowing varied over a considerable range, with some commercially-treated samples containing almost no insecticide (Lord et al, 1967). This obviously provided a possible explanation for the variable results obtained in practice and, in collaboration with the British Association of Seed and Agricultural Merchants and the British Agrochemicals Association, surveys of the amounts of insecticides and fungicides on seeds treated by currently available commercial seed dressing machinery were urgently undertaken (Lord et al, 1971b). The results showed that methods of applying both liquid and powder formulations were unsatisfactory. With powders, where the performance of three types of machine was examined, average loadings were usually well below the target. For example, in one survey only 5 out of 33 sets of samples from different merchants had an average loading greater than 50% of the target and the maximum loading was 70% (Table 1).

Table 1

Relative amounts of insecticide on seeds treated by different merchants with powder and liquid formulations (summarised from Lord et al, 1971b). Figures in each column give the number of sets of samples with the stated percentage of the target dose.

Type of dressing	Percentage of target dose						
	0-10	10-30	30-50	50-70	70-100	>100	Total
Powder	12	7	9	5	0	0	33
Liquid	0	1	6	5	3	2	17

Analysis of bulk samples indicated that loadings were on average nearer to the target with liquid formulations, with 2 out of the 17 sets of samples carrying more than the target dose, 8 carrying more than 50% and none carrying less than 20% (Table 1). However detailed analyses showed very large differences in the amounts on individual seeds with liquid dressings, the distribution being much worse than with powders. Thus some seeds carried 10 times the average load, 5-10% had more than twice the average load and 50-60% carried 25-75% of the average. The seeds examined had been treated by two different types of machine. In the first the liquid formulation trickles on to seeds passing through an inclined revolving drum. In the second the formulation is fed onto a spinning disc which produces a circular fan of droplets through which the seeds fall. Each method gave a distinctive pattern of distribution from seed to seed, the spinning disc giving slightly better results.

Because the loadings on seeds treated with powder dressings were so unsatisfactory, commercial methods of applying dressings were investigated to determine where improvements could be made (Jeffs et al, 1972). This investigation showed that powder and seed were generally mixed in the correct ratio in the mixing chamber but the powder did not adhere well and so separated from the seed after leaving the exit spout, both in the holding bins and during subsequent handling and drilling.

The results of these various studies have stimulated work to improve both formulations and seed-treating machinery. One major advance has been the development of the 'Rotostat' seed treater (Elsworth and Harris, 1973) which treats seeds by a batch process in a rotating mixing chamber and promises to improve the loading, adhesion and distribution of chemicals on seeds compared with conventional machines (Middleton, 1973). Jeffs (1973) has investigated methods of improving formulations and has shown that pretreating seeds under conditions which could be adopted in commercial practice with suitable adhesives such as polybutenes or vegetable oils could greatly improve adhesion of insecticidal powders.

Although control will obviously be unsatisfactory if most of the applied chemical falls off before sowing, it cannot automatically be assumed that strong adhesion is beneficial for other aspects of performance and it is necessary to have a good understanding of the biological requirements in order to suggest the most suitable formulations. Wheat bulb fly larvae move upwards in soil after hatching and probably reach the upper layers of soil where they search for a host plant, entering the shoot at a depth of 0.5 - 2.5 cm (Way, 1959). A seed treatment may therefore act by one or both of two processes discussed by Way (1959) who also distinguished two phases of attack. First the larvae may be killed in the soil around the treated seed as they move towards the plant through the diffuse zone containing chemical. Larvae which survive passage through this zone may cause a primary phase of attack on the shoots. Chemicals which are absorbed by the plant, however, may kill such larvae by systemic action. Those that are not killed tunnel within the shoot and kill the growing point of the plant before migrating to fresh plants to cause a second phase of attack. The exact modes of action and their relative importance vary with the chemical used. For example, Way (1959) found that dieldrin and aldrin reduce both primary attack, presumably by killing larvae in the soil before they enter the plant, and secondary attack presumably by killing additional larvae which survive the first process and enter the plant. With γ-BHC, however, toxicity depended more on the larvae being killed or deterred from feeding before they had significantly damaged the plant. Several organophosphorus insecticides also seem to act mainly by preventing the larvae from entering the bulbs (Griffiths and Scott, 1967). It seems possible that a combined treatment with two chemicals, one killing mainly in the soil and the other by systemic action, would be particularly effective. This may explain the very good results obtained with combinations of aldrin and chlorfenvinphos in recent trials, although exact comparison with single treatments is difficult because overall loadings were greater with the combined treatment.

Because seeds are sown in autumn and wheat bulb fly attack occurs in early spring, it follows that, whatever the mode of action of a chemical, it must be persistent and should remain localised around the seed to provide a protective zone in the soil or a source for uptake by the emerging seedling. Persistence as much as a particularly favourable mode of action, must be largely responsible for the success of dieldrin which has become the standard against which other treatments are compared, and although some of the more persistent organophosphorus insecticides such as chlorfenvinphos can give results as good as and sometimes somewhat better than dieldrin, they tend to be more variable probably because they are on the limit of their persistence (Dixon and Rogerson, 1972, Mathias and Roberts, 1973).

Redistribution of the chemical in soil from the initially localised seed dressing can occur by molecular diffusion and by leaching, both of which are retarded by adsorption of the chemical on soil particles. Most soil-applied insecticides and fungicides are moderately strongly adsorbed (See Hamaker and Thompson, 1972) and therefore relatively immobile in soil. In agreement with this, their apparent diffusion coefficients in soil lie in the range 10^{-7} - 10^{-8} cm^2/s (Graham-Bryce, 1969, Ehlers et al, 1969, Farmer and Jensen, 1970). The extent of redistribution by diffusion can be estimated for an idealised spherical seed from these figures using the relationship (Crank, 1955) :-

$$C = \frac{aC_o}{r} \ \mathrm{erfc} \left(\frac{r - a}{2\sqrt{Dt}} \right)$$

where C is the concentration at a distance r from the seed, after time t, C_o is the concentration at the seed surface, a is the radius of the seed, D is the diffusion coefficient and erfc denotes the error function complement. Table 2 shows calculated values of C/C_o (i.e. the concentration relative to that at the surface) after various times at a distance of 1 cm from each seed (approximately equivalent to the mid point between cereal seeds drilled uniformly at 125 kg/ha in rows 17 cm apart) and at a distance of 0.67 cm (equivalent to the mid point for a seed rate of 187 kg/ha) for a diffusion coeffient of 5×10^{-8} cm^2/s. These figures emphasise that transport by molecular diffusion in soil is slow.

Table 2.

Diffusion of pesticides from seeds : concentrations at a distance r from the seed after various time intervals (t) expressed as a percentage of the concentration at the surface.

r (cm)	t (days) 14	30	90	150
1.0	0.2	1.3	4.8	6.6
0.67	1.8	4.5	8.6	10.1

Transport by leaching is more difficult to estimate, because water movements fluctuate considerably, depending on the weather. However the likely orders of magnitude for redistribution by leaching may be estimated by assuming that only downward movement of water occurs and treating the soil as a crude chromatographic column. A chemical initially present as a point source is leached downwards as an increasingly diffuse conical zone. According to chromatographic theory the main insecticide front moves downwards at a rate f times the rate of movement of the water itself where f is the fraction of the chemical which is not adsorbed and is therefore freely mobile in the soil solution. For chemicals such as soil-applied insecticides which have distribution coefficients for adsorption on soil of about 20 (Hamaker and Thompson, 1972) f would be approximately 0.01 at 20% soil moisture content. It would therefore take 20 cm of rain, resulting in a net 100 cm of water movement in soil at 20% moisture content to move the front 1 cm. The extent of lateral spreading depends mainly on hydrodynamic dispersion. It can be shown that the width within which half the content of an initial point source will be found as a result of hydrodynamic dispersion after a mean depth of leaching l is given by $Y = 0.94\sqrt{dl/V}$ where d is the dispersion coefficient and V is the flow rate. Assuming representative values of 0.1 cm^2/day for d and 1 cm/day for V (Leistra, 1973) Y has a value of 0.31 cm. for a depth of leaching of 1 cm.

Although these calculations are idealised and based on many assumptions, they serve to emphasise that the mobility of chemicals used as seed treatments is very limited. In the case of the systemic fungicide, ethirimol, this limited mobility has been confirmed by direct autoradiographic measurements of soil cores containing seeds treated with C-14 labelled chemical (Graham-Bryce and Coutts, 1971); these studies also emphasised the importance of soil structural factors as well as adsorption in governing mobility. As pointed out earlier, such limited mobility is an essential property for the success of any chemical used as a seed treatment and would have contributed implicitly to its selection. Limited mobility also has important implications for the design of formulations to improve biological effectiveness, for example, there would seem to be little value in developing treatments which reduced mobility further for those chemicals which act by killing the insect in the soil before it reaches the root. This view is supported by the results of Jeffs (1973) who found that, although adhesion of γ-BHC was improved by treating the seed with polybutenes as discussed above, effectiveness against wheat bulb fly was decreased. Further, there is some evidence that, even without reducing mobility further by formulation, the performance of some chemicals which act mainly in the soil may be limited by restricted movement, particularly when seed is drilled deep and the zone of soil affected by the chemical is below the point of attack by the larvae. In such cases, chemicals such as dieldrin, which have systemic activity, appear to be at an advantage. Deeper sowing is likely to become more common with the advent of some modern herbicidal treatments for wild oat control, so that it may become increasingly important to have chemicals with this type of activity. For systemic action, increasing adhesion could possibly improve uptake via the seed and hence control; however results with the systemic fungicide ethirimol suggest that uptake by the emerging shoot and root near the seed is more important than uptake by direct entry from the seed so that even for systemic activity excessive adhesion could be of doubtful value. In tests with various ethirimol formulations, designed either to accelerate or delay release of the chemical from the seed, no significant improvements in performance over the standard 'col' formulation were obtained (Shephard, personal communication). Presumably faster release from the seed had little effect on redistribution which was controlled predominantly by the interactions of ethirimol with the soil, while delaying the release merely decreased the concentration available for absorption by the roots and shoot near the seed. Further investigations are underway at Rothamsted to characterise the release properties of different insecticide formulations and to establish which treatments give best control.

For many insecticides used to control wheat bulb fly greater adhesion could increase phytotoxicity if it increased penetration into the seed. However, recent results by Jeffs (1974) show that the phytotoxic effects of γ-BHC depend on how it is distributed on the seed surface, so that the effects of formulation on phytotoxicity may be complicated and difficult to predict. In laboratory tests, drops of γ-BHC in dimethyl formamide were applied to either the scutellum or the dorsal surface of wheat seeds which were then planted in soil and maintained in growth rooms at 20°C. After 9 days the emergence of shoots and extent of root growth were measured. Table 3 shows that treating the dorsal surface caused no harmful effects, whereas there was considerable damage when the drops were applied to the scutellum. The situation can be even more complicated when both insecticide and fungicide treatments are applied, because interactions between the individual chemicals may increase phytotoxicity.

Table 3.

Effects of γ-BHC on growth of wheat seedlings after application to either the scutellum or dorsal surface of seed at rates of 0.1 or 0.2 µl of 90 µg/ml solution in dimethyl formamide. Values are means of 4 tests, each with 10 seeds.

		Area treated				Standard error of mean
		Scutellum		Dorsal surface		
	untreated	0.1 µl	0.2 µl	0.1 µl	0.2 µl	
Mean length of longest root, mm	73.8	64.6	26.7	74.1	78.4	7.3
Mean number of shoots longer than 25 mm	9.25	8.0	3.25	8.75	9.75	0.52

In the light of this discussion of the biological requirements for control and the modes of action of the chemicals in use, it is interesting to consider the practical consequences of the low loadings and uneven distribution of insecticide found on commercially treated seed. The likely effects of poor loadings may be seen from the results of Griffiths et al, (1970) who examined the effects of different doses of powder formulations of γ-BHC, chlorfenvinphos and carbophenothion on seedling emergence and on damage by wheat bulb fly larvae. All the insecticides were ineffective at rates less than 10 μg/seed, but above these low levels, the percentage of damaged shoots and shoots containing live larvae progressively decreased with increasing amounts of insecticide. There was some phytotoxicity on a sandy loam soil, but none on peaty or clay loams. Comparisons with the surveys reported by Lord et al (1971b) indicated that the average amounts of γ-BHC present on commercially dressed seed would have given little or no protection under the conditions studied by Griffiths et al (1970) but that phytotoxicity would also have been unlikely. More recent results by Griffiths and Scott (1974) suggest that the dose/response relationship for dieldrin may be different: above a threshold value of about 10 μg/seed which gives satisfactory control, there is little further improvement as rates are increased. This is presumably related to the different mode of action of dieldrin and suggests that results with dieldrin should be less sensitive to variations in loading, which may be a further reason why dieldrin has proved relatively reliable in practice.

Although it would seem self-evident that the best control would be obtained when all individual seeds carried the same amount of chemical, the detailed biological consequences of non-uniform loading are difficult to predict. Even though mobility is limited, adjacent seeds would be expected to obtain some benefit from the chemical originally on neighbouring seeds, both in the case of systemic action and when kill takes place in the soil before attack. There is some evidence for this in the case of ethirimol (see below) but specific investigations of the effects of non-uniformity with chlorfenvinphos by Tuppen, (Lord et al, 1971a) showed that wheat bulb fly control decreased progressively as the distribution of chemical became less uniform. However on some soils more plants were damaged by the chemical with the more uniform treatments and this outweighed the effects on wheat bulb fly attack so that the best results were obtained when no insecticide was used. It would be interesting to do similar experiments with dieldrin where systemic action and prevention of secondary attack are apparently more important and phytotoxicity less (Way, 1959).

In considering the possible phytotoxic effects of seed treatments, it is helpful to distinguish two broad effects. At high loadings, such as those carried by a few seeds when distribution between seeds is uneven, tillers or plants are killed outright. In this case the survivors, particularly if they carry very little chemical, because of uneven distribution, can often compensate by greater growth and more tillering for the plants which are lost, so that yields may be maintained. At lower loadings there may be insufficient chemical to kill the plant, but growth may be retarded. If the lower loading is associated with more uniform distribution so that all plants are affected, compensatory growth cannot occur and yields will be reduced. This suggests that it may be necessary to re-evaluate phytotoxicity when methods of applying seed treatments more uniformly are introduced.

Satisfactory insecticidal seed treatments therefore have to meet several different requirements, some of which may be mutually conflicting. Ideally, the chemical itself must be safe to mammals and birds and be persistent (but not to the extent that it will cause problems in the environment), must not be excessively phytotoxic and must have a limited, but significant mobility in soil.

The formulation must adhere and be retained well so that it remains on the seed until sowing. However excessive adhesion may decrease effectiveness, particularly for chemicals which act mainly in the soil. Uniform distribution from seed to seed is desirable for good pest control, but may increase phytotoxicity. Possibly some form of sustained release formulation such as microencapsulation could provide the required pattern of persistence and distribution while preventing phytotoxicity, but this would undoubtedly be expensive.

FUNGICIDAL SEED TREATMENTS FOR CONTROLLING SEED & SOIL BORNE DISEASES

Organomercury compounds have been by far the most widely used fungicides for treating cereal seeds, and the phenyl and methoxyethyl mercuric compounds in particular are applied routinely in Britain. Application is by essentially the same processes as those used for applying insecticides. With powders combined formulations containing both insecticide and fungicide are available but with liquids the insecticide and fungicide are formulated separately and mixed as they fall onto the seeds. At first sight it might therefore be expected that treatment of seed with organomercury fungicides would be as unsatisfactory as with insecticides. However, analysis of single seeds (Lord et al, 1971b) showed that with both powders and liquids, mercury levels on the treated seed were much nearer to the target dose than were the associated levels of insecticide. For example, in one survey of powder dressings from 7 merchants the seeds carried an average of 82% of the target dose of mercury compared with only 52% for γ-BHC. Jeffs and Tuppen (1973) also found that mercury was much more uniformly distributed from seed to seed than γ-BHC.

The more uniform distribution of mercury is consistent with the accepted view that some redistribution of organomercury treatments can occur by vapour action in stored seed (Lindström, 1958). Such vapour action no doubt also contributes to the fungitoxicity of organomercury seed treatments by permitting some movement in the soil air space, and partly explains why they are so much more effective under practical conditions than inorganic salts. The importance of vapour action suggests that using adhesives to improve retention could decrease activity and should be considered carefully. However, discussion of how best to improve mercury treatments is difficult because very little is known about how they act or even of dose/response relationships for the main diseases which they control. Preliminary laboratory results from work recently started at Rothamsted (Bateman and McIntosh, personal communication) give an ED50 of about 0.1 μg/seed for control of seed-borne Septoria nodorum by phenyl mercuric acetate and about 1.0 μg/seed for complete control. These are in the same range as the levels applied in practice and found on treated seed in the survey by Lord et al (1971b), but of course much more work needs to be done to establish the best rates and formulations under practical conditions.

Although mercury fungicides have been used successfully for many years, their future is now uncertain, not so much because of problems of application, but because they are considered undesirable on toxicological grounds. Resistance is also a potential danger and has already been reported for Pyrenophora avenae, Fusarium nivale and Tilletia caries in limited areas. Several potential replacements have begun to appear, such as a combined carboxin - thiram treatment (Gunary, 1972) and a combined quinacefate - maneb treatment (Hocombe et al, 1973). Any satisfactory replacements for mercury should control the same wide range of diseases, which includes Pyrenophora, Septoria and Fusarium species as well as Tilletia caries. Traditional organomercury treatments have cost very little, so that to be immediately acceptable to the farmer, replacements should also be cheap. However in the long term the cost of new treatments should be assessed in relation to the economic return which they produce rather than to the cost of a less desirable traditional treatment and on this basis many suitable alternatives to mercury could probably be developed. The replacements will also be subject to the same problems of application as the traditional treatments and, unless volatile, they will lack the ability of mercury to be redistributed by vapour action. However systemic fungicides, such as carboxin, have a considerable potential advantage because they can penetrate the seed thoroughly and be translocated in the seedling without causingphytotoxicity. They can therefore control diseases such as loose smut which are contained well inside the seed, in addition to soil-borne diseases and the diseases which are present on or just beneath the seed coat. Formulation and application of this type of treatment may therefore have very different requirements from those applying to traditional organomercury fungicides.

SYSTEMIC FUNGICIDES FOR CONTROLLING FOLIAR DISEASES

Although several systemic fungicides, for example, benomyl and thiophanate compounds have been shown to control cereal leaf diseases such as mildew and rust when applied as seed dressings (Jenkyn and Prew, 1971), by far the best established example of this method is the use of ethirimol to control powdery mildew on barley.

The application of ethirimol to seeds appears to have been relatively free from problems. So far the chemical has been applied mainly as a 50% 'col' formulation in machines modified from those used to apply powders and working on the Archimedean screw principle. This formulation appears to adhere and be retained much better than powder dressings and in use there has been no evidence suggesting effects of uneven distribution. No doubt this is partly because much larger quantities of chemical are applied (up to 3.33 g.a.i. per kg.seed) compared with rates for conventional insecticide or fungicide dressings. However it is also possible that even distribution is less important for this type of chemical. It has already been emphasised that ethirimol has very limited mobility in soil (Graham-Bryce and Coutts, 1971). Further, more recent experiments by Coutts and Riley (1973; results to be published) indicate that when seeds treated with ^{14}C-labelled ethirimol are sown alternately with untreated seeds uniformly spaced at the average distance to be expected in the field, the amounts of radioactivity in plants from the untreated seed are only a small percentage of those in the plants from treated seed, suggesting that there is very little sharing of chemical by adjacent plants. Nevertheless there is some indirect evidence that under field conditions adjacent seedlings may tap chemical originally present on neighbouring seeds. For example, Purnell (personal communication) found in a very thorough series of field trials comparing a range of loadings from 2.2 to 8.9 g.a.i./kg at seed rates from 62.5 to 250 kg/ha that, over a wide range, control of mildew was related more to the overall rate of chemical applied per acre rather than the rate per seed. It seems possible, therefore, that under field conditions where seeds are drilled much less uniformly and often cluster fairly closely in some patches that more significant sharing of chemical may occur, provided the seed rate is not too low. The occasional more isolated plant in the row would then be at a disadvantage, particularly if it happened to carry a relatively low loading, but overall control wouldprobably benefit.

In general, therefore, the application of systemic fungicides to seeds has been successful and satisfactory disease control has been achieved. However, it is probably not generally realised how little of the applied chemical is taken up and translocated to the foliage with this method. The results of Graham-Bryce and Coutts (1971), for example, show that amounts of ethirimol reaching the foliage of barley are likely to be less than 5% of the amounts applied to the seeds and similar results could be given for other systemic fungicides and insecticides.

These figures are perhaps not surprising because, although such compounds are not usually rapidly degraded and can be absorbed by almost all underground parts of the plant in the region of application, (including the stem, roots and possibly the seed itself), they also have limited mobility. This is clearly an advantage in the early stages of growth as discussed above, but it results in the most actively absorbing parts of the root growing progressively away from the chemical as the plant becomes older. It is difficult to suggest ways of overcoming this, but ultimately this very poor utilisation of chemical may offer the biggest scope for improvements in formulation.

THE FUTURE

In recent years there has been a tendency for seed rates to decrease, so that with barley, for example, rates of 125 kg/ha are now common. This trend is likely to continue, particularly if expensive hybrid seeds are introduced, and it is not unreasonable to look forward to rates as low as 60 kg/ha. At the same time many more chemical seed treatments for controlling pests and diseases will probably be introduced so that the total quantities of chemical to be applied could become considerably larger than at present. Both these trends may introduce new problems of adhesion and distribution and will almost certainly require the development of new formulations and methods of application. At high loadings also, the flow characteristics of the seed will be affected, with consequent effects on drilling.

Ultimately if cereal yields are to continue increasing, more precise methods of placing the seed during sowing may be needed, both with regard to depth in the soil and evenness of spacing along the row. This, together with the trends towards smaller seed rates and heavier loadings may lead to the introduction of pelleted seed which, although expensive, could offer many advantages. The requirements for successfully incorporating pesticides into pelleted cereal seed are largely unknown, however, and the development of this technique would almost certainly require much further research.

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THE PROBLEM OF PEST AND DISEASE FORECASTING - POSSIBILITIES AND LIMITATIONS AS EXEMPLIFIED BY WORK ON THE BEAN APHID, APHIS FABAE

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Summary General problems of forecasting the need for, and timing of control measures against pests and diseases are discussed and are exemplified by current work on the bean aphid (*Aphis fabae*) attacking spring sown field beans.

Crop losses of spring beans are related to the proportion of plants colonised by alatae migrating from the spindle tree (*Euonymus europaeus*) during the first three weeks in June. The figure of 5% of plants colonised in the S.W. or S. side of a field is being used as the 'economic threshold'. Forecasts of aphid colonisation are being made in co-operation with ADAS entomologists in nineteen areas covering almost all of England south of the Humber. They are based on counts of aphid eggs between December and January, and of active stages in mid-May on sample spindle trees. Corrections are made for effects of differences in abundance of spindle and of bean aphid-attacked crops in the different areas.

At present the forecast for each area is made first in February as follows:- 'unlikely' (<5% of initially-colonised bean plants expected) = chemical control probably unnecessary; 'possible' (5 - 10% expected) = be prepared to apply control measures but first check individual fields at the advised time; 'probable' (>10% expected) = control measures necessary on great majority of fields so apply insecticide at the advised time. A second forecast in late May indicates when, if needed, the insecticide should be applied.

Most area forecasts have so far provided effective early warning of need for, and time of insecticide application. There were anomalies in two small areas - S. Downs and S. Essex which seem to be high-risk areas annually; also once in S. Somerset. The scheme needs to be refined and tested in all areas for several more seasons.

It seems likely that numbers of bean aphids on the weed *Chenopodium album* in September and of alatae caught by 'Rothamsted' suction traps in autumn can be used as a basis for preliminary forecasts.

Present evidence indicates that the times and intensities of bean aphid infestations can be forecast more accurately than for other important aphid species attacking annual crops.

Résumé Les problèmes généraux de prévision de la nécessité d'intervention, et de la détermination du moment favorable aux mesures de lutte contre les pestes et les maladies sont discutés et illustrés par des exemples tirés des travaux en cours sur le puceron des fèves (Aphis fabae) attaquant les fèves de printemps semées dans les champs.

Les ravages sont exprimés par la proportion de plantes colonisées par les ailés venus du fusain (Euonymus europaeus) pendant les trois premières semaines de juin. La proportion de 5% des plantes colonisées dans la partie S.O. ou S. d'un champ sert de 'seuil économique'. Les prévisions de colonisation par les pucerons sont faites en collaboration avec les entomologistes de l'ADAS dans dix-neuf régions couvrant presque toute l'Angleterre au sud du Humber. Elles sont basées sur le nombre d'oeufs de puceron compté entre décembre et janvier, et des stades actifs à la mi-mai sur des échantillons de fusain. On corrige pour tenir compte des effets de la différence d'abondance de fusain, et des recoltes de fèves attaquées par les pucerons dans les différentes régions.

Actuellement, la prévision pour chaque région est faite en février de la façon suivante:- 'improbable' (on s'attend à moins de 5% de plants de fève initialement colonisés) = moyens de lutte chimiques pas nécessaires; 'possible' (on s'attend à de 5 à 10%) se préparer à appliquer des mesures de lutte mais d'abord, verifier chaque champ individuellement ou moment conseillé, 'probable' (on s'attend à plus de 10%); les mesures de lutte sont nécessaires pour la grande majorité des champs; donc, appliquer des insecticides au moment conseillé. Une 2ème prévision fin mai indique, quand besoin est, le moment favorable à l'application des insecticides.

La plupart des prévisions régionales, ont jusqu'à maintenant, fourni de bonne heure des avis valables pour la nécessité et le moment favorable pour l'application des insecticides. Il y a eu des anomalies dans deux petites régions - S. Downs et S. Essex - où il semble que les risques soient élevés tous les ans; de même une fois dans le sud du Somerset. Il faudra, là, raffiner les schémas et vérifier toutes les régions pendant encore un bon nombre de saisons.

Il semble probable que le nombre de pucerons ailés sur Chenopodium album en septembre, et d'ailés attrapés par les pièges à succion de 'Rothamsted' en automne, puisse servir de base pour des prévisions préliminaires.

Les résultats obtenus indiquent que l'époque et la densité d'infestation des pucerons de la fève peuvent être prévues avec plus de précision que pour d'autres importantes espèces de puceron attaquant les récoltes annuelles.

INTRODUCTION

Nowadays there is no need to elaborate on the many different reasons which make it increasingly important to apply chemical pesticides only when needed rather than as a routine insurance. Hence the emphasis on importance of forecasting. Pest or disease forecasting usually has two main functions:- to predict whether a pesticide will be needed and to indicate when it should be applied. Ideally, the prediction of need should be based on detailed knowledge of the minimum pest density that justifies the cost of the control measures; but this important concept of the 'economic injury threshold' proves elusive in practice. We must therefore appreciate the errors in assessing crop losses in relation to forecasted pest incidence and, in doing so, attempt to distinguish those problems where the errors are seemingly inevitable from those where improvements are possible.

CROP LOSS ASSESSMENT

At an earlier British Insecticide and Fungicide Conference, Croxall (1965) gave a recipe for plant disease assessment and added that the major ingredient was "a lot of hard work". This partly explains the few major attempts to do this quantitatively, outstanding examples with insect pests being aphids on sugar beet (Hull, 1968), frit fly, (Oscinella frit) on oats (Strickland, 1958, 1970) and cabbage aphid, (Brevicoryne brassicae) on brussels sprouts (Strickland, 1957). Such work defined overall year to year crop losses and provided the background for decision-making on whether and when to apply appropriate insecticides. However, even this extensive work did not accurately define economic thresholds for particular fields and, with brussels sprouts, for example, much of the data is not now relevant to the changed methods of growing and processing the crop.

Pests of apples provide contrasting examples of present problems. Apple sawfly (Hoplocampa testudinea) destroys fruitlets and could be a beneficial 'thinner' in some seasons, but in other seasons, when natural fruit set is poor, it can cause notable crop loss. Where apple sawfly is prevalent, routine chemical control will therefore remain unavoidable unless it becomes possible to predict or regulate natural fruit set. In contrast to apple sawfly, the fruit tree red spider, (Panonychus ulmi) feeds damagingly on the leaves after the fruit has set. Relationships between mite numbers and crop loss can be defined, as indicated by work of ADAS entomologists (Coghill, 1969) but a valid basis for economic thresholds has not yet been established. The fruit tree red spider mite and allied species throughout the world are among the few key species upon which the development of fruit tree pest and disease control strategies crucially depend. It is, therefore, surprising that so little of the enormous amount of research on them has been devoted to assessing critical damage levels.

Besides difficulties in assessing damage relationships of a single pest species, there are the interacting effects of different pest and disease species; thus Strickland (1965) refers to evidence of much greater yield losses from collective action than if the pests had acted independently; but the converse can also occur sometimes e.g. seemingly with jassids and whitefly on Sudanese cotton (Joyce, 1959) and with cereal cyst nematode, (Heterodera avenae) and take-all fungus, (Ophiobolus graminis) on barley (Cook, 1969).

Clearly the effective assessment of crop loss, especially at the level of the individual field, is a formidable proposition. There is, however, much room for improvement, particularly in correcting over-estimates of expected loss, as in many situations where apparently alarming injury can be compensated for by the plant. This was strikingly demonstrated for leaf chewing insects attacking seedling sugar beet (Jones, 1953; Jones, Dunning & Humphries, 1955) and by the ability of many plants to compensate for seemingly severe losses ofyoung shoots or flowers (Southwood & Norton, 1973). This attribute partly explains why, for two major pests of much studied Californian cotton, the estimates of densities needed to cause economic injury have recently been greatly increased (Gonzalez, 1970; van den Bosch et al, 1971). Besides the plants' ability to compensate for injury there are also implications from work referred to by Southwood and Norton (1973) that sometimes crop yields can even be increased by insect injury!

Finally, the expected crop loss must be costed in relation to the cost of control. Some of the economic complications were classically discussed by Ordish (1952) and have been highlighted by recent unpredicted changes in grain prices, for example the sudden doubling in value of field beans in the year 1973. Strickland (1966) refers to situations where the diagnosis may cost more than a routine prophylactic treatment and also (Strickland, 1970) to the growers' natural tendency to "play safe" especially with high-value crops where routine pesticide application is cheap relative to the overall cost of production. However, decisions will increasingly be influenced by criteria such as need to preserve the pests' susceptibility to the pesticide, and also by environmental constraints not directly connected with control of the pest (Southwood & Norton, 1973). In developing more rational methods for decision-making on pesticide application there is the still evolving object lesson of British research on sugar beet pests and of essential collaboration exemplified by research workers, advisors and farmers in the sugar beet industry. As a first step we can surely establish some crude economic injury criteria where none exist, and improve on others (Strickland, 1960) which are mostly inspired guesswork. As an example, valuable economic thresholds have been defined for apple pests in Western Europe (Anon, 1971). There is little factual evidence for many of them but they nevertheless provide the essential basis for subsequent refinement.

WARNING AND FORECASTING

Short term warning schemes, often based on examination of newly colonised crops are widely used to indicate impending damage by many insect pests and for timing insecticide applications. They can be time consuming, expensive and inconvenient and may require a 'fire brigade' response. In contrast, an early warning or forecasting scheme also aims to anticipate need sufficiently to give adequate time for the advisory services, the service industries and the farmer to make, or avoid having to make, preparations for control measures. The accuracy of forecasts, and whether they are generalised or are applicable to individual fields varies according to the pest or disease species, particularly whether it is soil or air-borne.

Soil-borne pests and diseases

The relative ease with which the abundance of some relatively immobile soil-organisms can be predicted with long term accuracy is seldom highlighted as a success-story for long term forecasting. Given some knowledge of the residual population of the pest or disease and of soil conditions in a particular field, the order of losses likely to be caused by certain pathogens such as take-all, and nematodes such as potato cyst eelworm, (*Heterodera rostochiensis*) or sugar beet cyst eelworm, (*Heterodera schactii*) can be usefully predicted according to subsequent cropping sequences (Empson & James, 1967; Glynne, 1965; Jones, 1969, 1972; Jones & Dunning, 1969; Strickland, 1970). At present such long term knowledge is not always relevant to use of pesticides but is mostly the basis for essential decision-making on long term crop rotations for optimising crop yields (Empson & James, 1967; Jones, 1972). Populations of some other 'soil'-borne pests such as millipedes, slugs, symphylids and Collembola should also be predictable as Wallace (1957) has shown with *Sminthurus viridis* attacking pastures in Western Australia. Furthermore, as pointed out by Professor F.G.W. Jones (priv.comm.) some air-borne insects can sometimes be regarded as 'immobile' because they have long-lasting larval stages in the soil. Hence, useful forecasts can be made of outbreaks of wireworms (*Agriotes* spp) (Stapley, 1949) and some chafer species attacking grassland which are essentially 'immobile' because the females tend to oviposit where they emerge. Consequently, in several countries, control of such species is based on timely insecticide treatment of foci of infestation from which the pest would otherwise predictably spread in succeeding years. The relatively stable and equable soil climate no doubt helps to minimise errors in forecasting some soil pests and diseases, in contrast to those attacking above ground parts of the plant, especially ones that are sensitive to vagaries of weather during crucially important periods overwinter or during dispersal.

Air-borne pests and diseases

There are striking examples from forestry where cyclical outbreaks of certain insects can be forecast many years in advance (Graham, 1956). This is partly because many species that live in the vegetatively stable perennial tree crop environment tend to disperse locally (Southwood, 1962). Such localisation consequently makes it possible to forecast freedom from significant codling moth (Carpocapsa pomonella) damage in some English orchards for several seasons following one when the pest has been effectively controlled by an insecticide (Dr.G.H.L. Dicker, priv.comm.).

The irregular outbreaks of some relatively slowly reproducing species can be usefully forecast on the basis of a sequence of particular weather conditions e.g. the red locust, (Nomadacris septemfasciata) (Symmons, 1959). In Britain, some annual crop pests such as wheat bulb bly (Leptohylemyia coarctata), (Long, 1960), cereal aphids (Kolbe, 1970) and beet fly (Pegomyia betae), (Jones & Dunning, 1969), periodically become especially abundant for several seasons and, while some causes are known (Raw, 1967), we need to know very much more, particularly for the many British pests with year-to-year fluctuations that at present cannot be explained.

Weather favourable for multiplication and infection can in a few days or weeks transform the status of diseases such as potato blight, (Phytophthora infestans) (Beaumont, 1947; Smith, 1956) and barley mildew, (Erisyphe graminis) (Polley & Smith, 1973). Consequently, appropriate meteorological criteria have been successfully used to forecast epidemics, though whether they fully materialise or what economic losses they will cause is another matter (e.g. Lester, 1971). Some insects with rapid powers of multiplication can also predictably become a problem during short periods of favourable weather but it is our inadequate knowledge of their relatively complex responses to weather that at present may limit our use of weather data as a helpful tool in forecasting incidence of so many British crop pests. Exceptions include species which are harmed by severe winter weather notably some aphids which overwinter as active stages (Carter, 1972; Watson, 1966, 1967).

Imaginative and detailed research has been done on certain British pests in the last two decades, for example, on pea moth, (Laspeyresia nigricana) (Wheatley & Dunn, 1962), cabbage root fly. Erioschia brassicae, (Coaker & Finch, 1971) and wheat bulb fly (Long, 1960; Bardner et al, 1970), but even this has not led to significant improvements on earlier procedures whereby insecticide applications against pea moth are made when the first adults or eggs are found in sample crops (Gould & Legowski, 1961), whereas cabbage root fly is still controlled by routine insecticide treatment which, however, can now be timed better than before (Coaker & Finch, 1971). Bardner, Maskell & Ross (1970) point out that little practical advancement has been possible in improving precision of damage assessment and forecasting of wheat bulb fly attacks, which still depend mainly on criteria established about twenty years ago (Gough, 1947, 1953). This is no reflection on the work that has been done, because frequently, as with wheat bulb fly, complex interactions of soil conditions, fertility, date of sowing and unpredictable weather can dramatically alter predictions made from egg populations or even as late as when the plants have already been injured (Gough, 1953; Bardner, Maskell & Ross, 1970). It is in the context of such inherent difficulties in forecasting incidence and the relationship between incidence and the amount and cost of the damage caused (Jones & Jones, 1964; Way, 1973) that our present work on the bean aphid, (Aphis fabae) should be judged.

WORK ON THE BEAN APHID - YEARS 1969 - 1973

In Britain the bean aphid overwinters almost exclusively as eggs on the spindle tree, (Euonymus europaeus). Work on forecasting infestations on sugar beet crops, based on prior counts of overwintering eggs on spindle, was undertaken by Advisory Entomologists in the 1940s and showed promising correlations between egg numbers and size of infestations on seed beet in East Anglia (Jones & Dunning, 1969). The present studies began because ADAS entomologists pointed to the need for a forecasting scheme for bean aphid attacking field beans. At the time, in 1968, some farmers adopted no control measures or, if they did, they delayed treatment until damaging aphid populations had already developed. Others applied insecticides themselves as a routine treatment or had to because they were dependant on advance contracts. Furthermore, it was evident that advice was needed on timing of insecticide application to ensure success from a single insecticide treatment (Way, 1955). Accordingly, a programme of sampling was devised and initiated in 1969 by ADAS, research institute and Imperial College entomologists, and it now covers most of England south of the Humber.

General Methods

Records are being made on more than three hundred and thirty designated spindle bushes in England south of the Humber. It is envisaged, however, that many fewer, chosen because they are the best indicator bushes, will be adequate in future. Overwintering eggs on sample twigs are counted in December or January and numbers of active stages are estimated at the time of about peak population between mid and late May, just before the main migration of alatae from spindle to crops. The data on active stages is expected to give the best indication of the numbers of aphids migrating to crops; a simple examination for winged stages also indicates the time of migration to crops and hence the best time for insecticide application, if required.

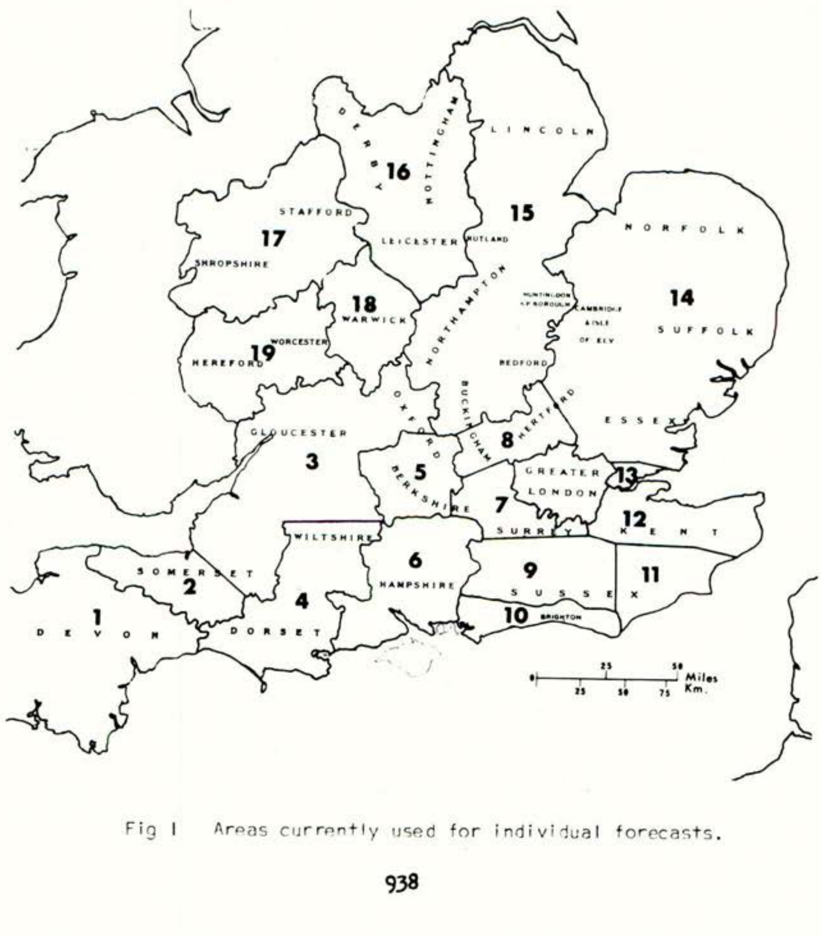

Fig I Areas currently used for individual forecasts.

It is known that field bean crops in certain areas are more prone to bean aphid attacks than in others, so, as information accumulated, nineteen 'areas' were designated (fig.1) partly on this basis and partly, for convenience, on ADAS 'Regions'. Separate forecasts were then made for each area according to the local spindle data. The areas vary greatly in size, and some, notably the very large 'East Anglia' (area 14) will no doubt justify radical revision as more information accumulates about local variation.

The success of 'area' forecasts depends on the assumption that alatae responsible for significant crop colonisation fly relatively short distances, often less than five miles and seldom more than about twenty miles before settling. Much of the work on flight of the bean aphid (Taylor, 1965) conforms with this assumption as does the evidence of alate aphids leaving a mangold clamp, most of which landed within half-a-mile of the clamp (Heathcote & Cockbain, 1966). Abroad, large numbers of some aphid species may migrate long distances (Taylor, 1965; Johnson, 1969) but there is no evidence yet that significant numbers of bean aphids do this in Southern England, at any rate at critical times for crop colonisation in May and June.

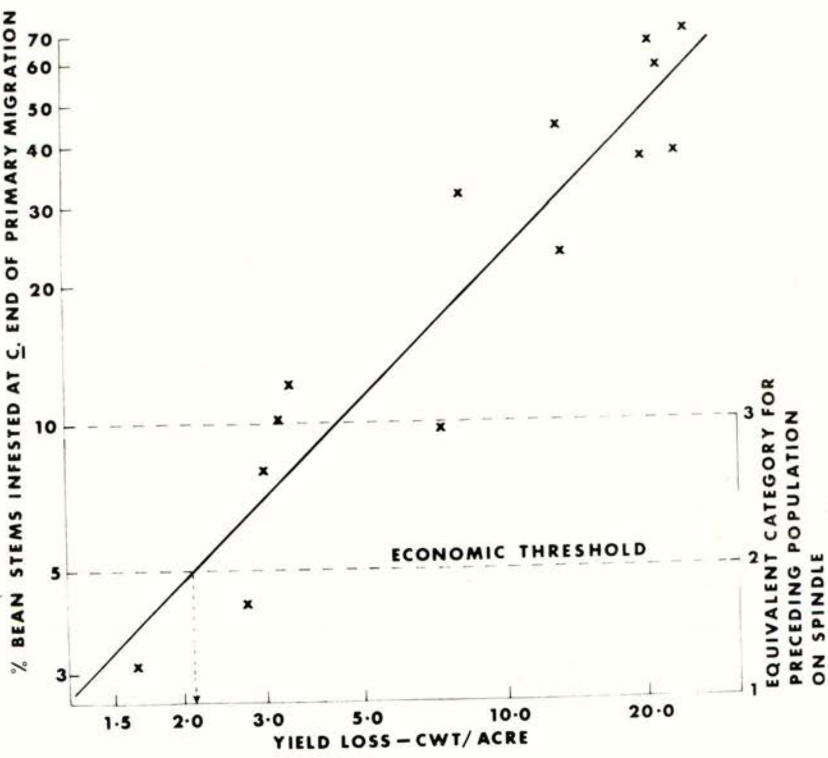

Fig.2 Relationship between % stems initially colonised by A. fabae and yield loss, based on 25 cwt/acre on aphid-controlled crops.

Assessment of the 'economic threshold'

The bean aphid is controlled chemically on most bean crops, so crop losses could not be determined directly on farmers' fields. Records were however made on farm crops of the proportions of stems colonised at about the end of the primary migration from spindle i.e. just before the time when an insecticide should be applied. Sampling was done in the S.W. or S. edge of each field where the prevailing wind would usually carry most colonists. The relationship between proportion of stems infested and crop loss was obtained from records of previous field plot experiments with field beans sown in March at a density of about 200,000 plants/acre, mostly at Rothamsted (Way, 1967; Way et al, 1958). The crop losses from bean aphid attack on untreated plots were calculated in terms of a 25 cwt/acre yield on plots where the aphid was controlled by a systemic aphicide, (fig.2). Five per cent colonisation caused a mean loss of about 2.1 cwts/acre (fig.2), valued at £5.25 on the basis of £50/ton. This was defined as the 'economic threshold' even though it represents more than the cost of chemical control (about £3 per acre in 1973). However, there is no doubt that the chosen sampling procedure overestimates overall colonisation. This is because it is well known that field edges, especially the sides from which come the prevailing winds, are notably more colonised than the rest of the field (Taylor, 1962). Fig.3 is an extreme example of a field where the percentage stems colonised by primary migrants ranged from 63% in one corner to 0% in part of the interior of the field. More than 5% initial infestation would therefore be needed at the S. or S.W. edge to cover the cost of applying an insecticide to a whole field, although less than 5% might justify control measures along the edges of a field. Hence the choice of 5% as a compromise economic threshold.

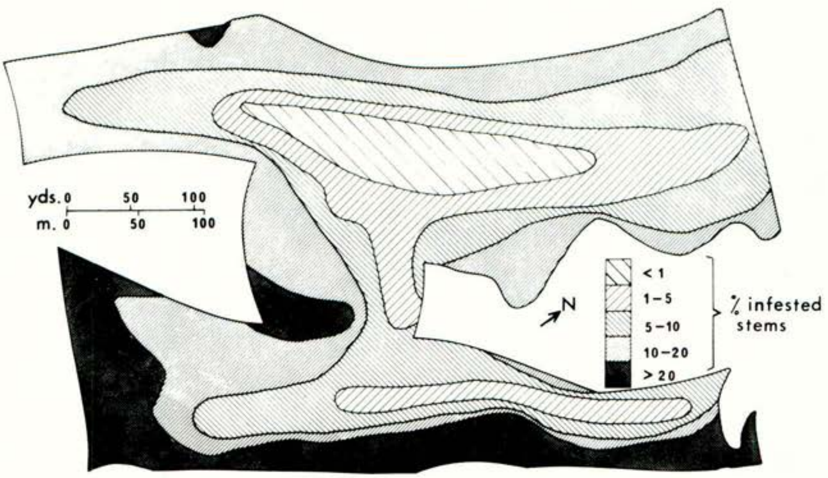

Fig.3 Pattern of infestation of a spring sown field bean crop (North Farm, Sussex) as indicated by % stems colonised by A. fabae on June 1st 1973

Within-field variation in bean aphid infestations is also characteristic of many other crop pests and so accounts for some of the imprecision that we must accept in damage assessment and hence in forecasting need for control measures. Furthermore, there is field-to-field and also season-to-season variation in the crop-loss caused by similar initial infestations, as is evident from fig.2. An extreme example is recorded in the West Midlands (J.M. Rayner priv.comm.) where spring beans on one farm are seemingly little damaged by bean aphids colonising more than 10% of the stems. Local modifications based on the farmers' experience are, therefore, vital to any forecasting procedure.

Relationship between numbers of aphids on spindle and numbers colonising spring bean crops

A comparison of mean number of stems initially infested at the S. or S.W. edges of crops, and mean numbers of eggs on samples from local spindle indicated that 5% initial infestation corresponded best with an average egg population of 1 - 5 eggs per 100 spindle buds. The mean egg populations on spindle were categorised as follows:- category 1 = <1 per 100 buds; category 2 = 1 - 5; categories 3 onwards = >5. A category of <2 was forecast to be equivalent to $<5\%$ infestation of bean stems in the S. or S.W. of a field = damage unlikely = control measures unnecessary. A category of 2 - 3 was considered equivalent to 5 - 10% crop infestation = damage possible = decide on control measures after examining the crop. A category of >3 was considered equivalent to $>10\%$ crop infestation = damage probable = control measures usually justified without need to examine the crop.

It was soon realised that correction factors were needed in some areas to allow for large differences in abundance of spindle and to a lesser extent for varying abundance of susceptible crops. Thus sample data given in terms of eggs or aphids per unit of spindle (e.g. per 100 spindle buds) will underestimate the numbers of potential crop colonists where spindle is common and overestimate them where it is scarce. Furthermore, in areas where sugar beet and beans are relatively commonly grown, the available aphids would be diluted amongst the crops, with fewer per crop than where susceptible crops are scarce. Fig.4 shows provisional corrections for 'Hampshire' (fig.1, area 6), 'East Weald' (area 11) and 'East Anglia' (area 14). The damage potential is greatly increased in Hampshire by the exceptional abundance of spindle (approx.6 x the average) whereas it is decreased in East Anglia where there is much 'diluting' sugar beet. Elsewhere, smaller corrections are needed.

Table 1. Accuracy of area forecasts of A. fabae attacks on field beans for the years 1969-1973 based on aphid populations on spindle

	Number of forecasts	Number correct	Number where infestations were larger than forecast
Crude Data	60	44	8
Data corrected for area abundance of spindle and other crops	60	52	5
Corrected data excluding South Downs & South Essex areas	53	49	1

Results of area forecasts

Table I shows that about a quarter of the forecasts from uncorrected counts of bean aphids on spindle were wrong because primary infestations on the average bean crop did not substantiate predicted 'unlikely', 'possible' or 'probable' infestations. However, when the data were corrected to allow for the 'area' abundance of spindle and of other susceptible crops (fig.4) the proportion of incorrect forecasts fell to one eighth. All forecasts were correct in the year 1973.

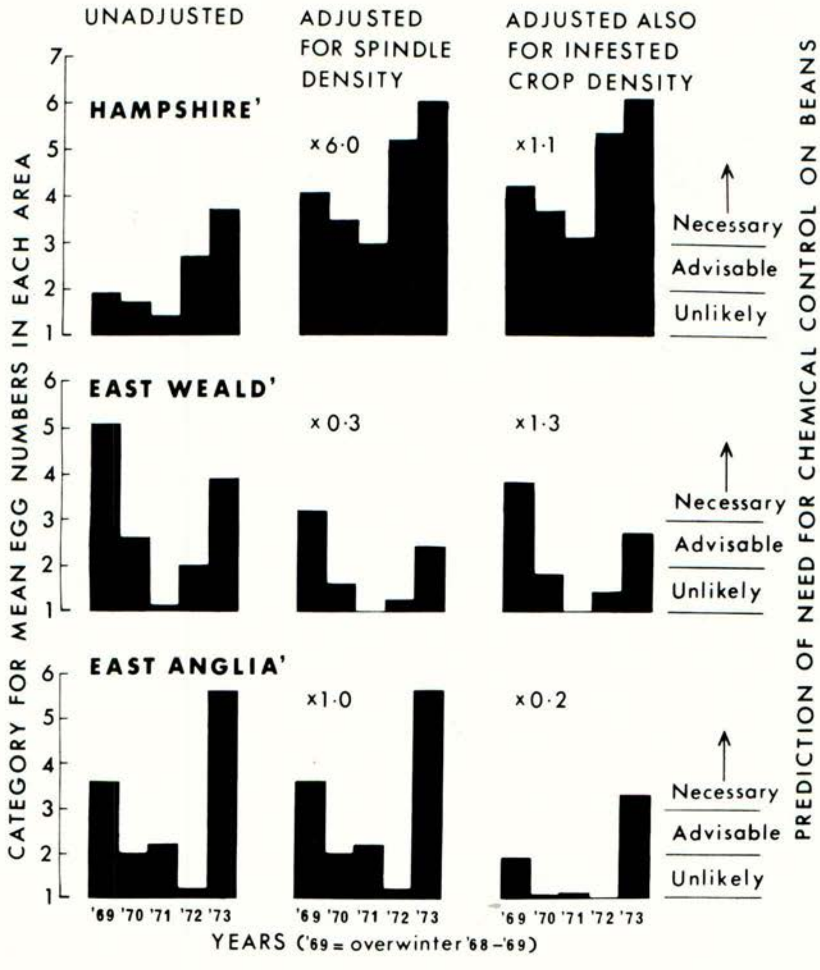

Fig.4 Provisional adjustments to sample populations of overwintering A. fabae eggs to allow for differing area abundance of spindle trees and susceptible crops.

In practice, an incorrect forecast is worst if it under-estimates the ultimate crop loss; the corrected data show that this happened in 1971 and 1972 in five (one twelfth) of the forecasts. However, four of these were in the relatively very small South Downs and South Essex areas, the other being in S. Somerset (area 2) (table 2).

Table 2. Details of underestimated forecasts of crop infestations

Area	Year of incorrect forecast	Forecast based on spindle counts	% Colonisation of field beans
S. Downs	1971	Unlikely (<5%)	Mostly >10%
	1972	Unlikely (<5%)	3 to 10%
S. Essex	1971	Possible (5-10%)	Mostly >10%
	1972	Possible (5-10%)	Mostly >10%
S. Somerset	1972	Possible (5-10%)	Mostly >10%

The bean aphid is well known as a special problem in S. Essex and we have been able to define the limits of the severely attacked crops as a very small area south of Brentwood and west of Southend (fig.1, area 13), which has contrasted strikingly with the relatively lightly colonised area immediately to the north, except in the epidemic year of 1973. This is not peculiar to bean aphid because cereal aphids are also unduly abundant in this part of S. Essex (George, 1974). Possible causes of the anomalies on the S. Downs and in S. Essex, include sea breeze front effects, migration from the Continental mainland and unappreciated sources of overwintering in parks and gardens in the London area or along the South coast but, for practical purposes, it is sufficient to define them as very high risk areas where severe crop damage is inevitable whenever overwintering aphid eggs are common on the local spindle, and is also probable even when they are scarce.

The only other major anomaly was in S. Somerset (fig.1, area 2) in the year 1972 when up to 33% of stems was infested on field-bean crops in the Vale of Taunton although little more than about 5% was forecast. In the other main field bean (and sugar beet) areas, the forecast have been reliable. The year 1973 was, as predicted, an epidemic year throughout almost all of Southern England but, in the previous three years, sample crops in Hampshire and parts of the West Midlands had predictably damaging infestations while crops in much of a large region from Oxfordshire widening eastwards to East Anglia and E. Midlands were, as anticipated, sparsely colonised.

Field to field variation

Except where already indicated, the area forecasts have been accurate for the 'average' spring bean field in each area. However, the crunch comes, as with any area forecasts, when the accuracy of the forecast is tested against individual fields. Appropriate data are given in table 3 for the years 1971 to 1973 in two important bean growing areas.

As already mentioned, a forecast is especially unacceptable when it significantly underestimates the ultimate damage. This has seldom happened except in the anomalous areas (S. Downs, S. Essex, S. Somerset). Crop colonisation was, however, larger in Hampshire in the year 1971 than would have been expected from the borderline >10% colonisation that was forecast (table 3).

Table 3. Relationship between results of sample field counts and forecasts in two main bean growing areas, years 1971 - 73.

	Year	Area forecast of % stems colonised	% of sample fields with:- < 5% stems colonised	5-10% stems colonised	>10% stems colonised
East Anglia					
	1971	< 5	95	5	0
	1972	< 5	100	0	0
	1973	> 10 (borderline)	8	16	76
Hampshire					
	1971	> 10 (borderline)	0	11	89
	1972	> 10	6	31	63
	1973	> 10	0	0	100

Otherwise forecasts have erred safely towards overestimation of anticipated infestation especially in the year 1972 as shown by the Hampshire data and more strikingly in Hereford/Worcs. data where a definitively forecasted >10% colonisation was recorded in only 74% of fields. Sometimes it has not been possible to examine sample fields at the best time. However, this does not explain much of the observed variation, which highlights the generally inadequate understanding of causes of field-to-field variation in infestation of many other species of pests and diseases. Date of sowing and density of the crop greatly affect colonisation, with time of immigration of the pest acting as an important modifying factor (Way, 1967; Way & Heathcote, 1966). The use of % stems infested as a criterion of colonisation must also create errors if plant density is variable, as it often is. Surrounding shelter increases colonisation by some pests especially at field edges (e.g. Lewis, 1969). Field size, grouping of field bean and sugar-beet crops, the topography of fields and of surrounding land and perhaps proximity to large areas of water may also affect colonisation. Work in progress should enable us to designate 'high risk' and 'low risk' characteristics of fields in ways that will be helpful to the adviser and to the farmer.

POSSIBILITIES OF FORECASTING DAMAGE BY OTHER IMPORTANT CROP APHIDS

Several characteristics of the life cycle and behaviour of the bean aphid seem favourable for forecasting work. Firstly, there is one important winter host which is localised and easily identified and, in the main bean and sugar beet areas, is virtually the sole source of aphids colonising crops in May and June. Secondly, the overwintering stage is an easily sampled egg which seems to be little affected by vagaries of weather (Way & Banks, 1964). Thirdly, there is usually a well defined migratory period to crops, at the end of which, a single correctly timed insecticide application should give effective control. Fourthly, the evidence that crop loss is related to numbers colonising the crop makes it possible to define an economic threshold on which to base timely practical decisions on control measures.

Can we do as well with other pest species, especially other aphids? The following data indicate how the qualities of some other important crop aphid species measure up to those of the bean aphid.

The peach-potato aphid (Myzus persicae) on sugar beet

Unlike bean aphid, this species is a low-density pest important only as a virus vector. It overwinters mostly as active stages on many different species of weed and crop hosts of which sugar beet virus-infected species are the most important. It is very difficult to find and assess the relatively small over-wintering populations. Many over-wintering aphids are killed in cold winters which predictably decrease early virus spread (Hurst, 1965; Watson, 1966). Sticky trap and 'Rothamsted' suction trap catches indicate when the first alate migrants are flying to crops (Watson & Heathcote, 1966; Heathcote, Palmer & Taylor, 1969) and, as data accumulates, may also help to indicate abundance. There is no well defined migratory period, unlike A. fabae, but migrants arriving during a variable period in May-June are especially important as vectors of sugar beet viruses (Hull, 1968). The relationship between numbers arriving on crops and ultimate crop loss is, however, complicated by unpredictable variation in proportion of aphids which are viruliferous. Control depends on a short term warning scheme based on counts of the first colonists on sugar beet fields. The economic threshold requiring immediate insecticide treatment in yellows virus prone areas was initially set at a mean of 0.25 per plant (Hull, 1961), but advice is now modified according to region and date (Hull, 1967, 1968). Apart from evidence that virus spread is usually worst following mild winters, there are at present few clues for developing a forecasting procedure.

Sitobion avenae, Metapholphium dirhodum and other cereal aphids

S. avenae overwinters on grasses and winter cereals as both eggs and active stages. M. dirhodum also overwinters on grasses and as an egg on certain Rosaceae. The widespread distribution of overwintering hosts and the probable susceptibility of active stages to cold in winter makes it difficult to make early forecasts of likely size of migration to spring cereals. Initial infestations of particular fields must vary according to abundance of 'diversionary' grass and cereal crops in the neighbourhood. Whilst it is known that the maturity of the crop influences colonisation and crop loss (Sparrow, 1974), serious lack of knowledge of the influence of diversionery crops and of other factors that affect field-to-field variation in colonisation is a limitation that must be rectified before 'Rothamsted' suction trap data can be fully tested as a means of forecasting degrees of colonisation of particular crops. However, the trap catches can usefully predict the time when colonists should begin to arrive (George, 1974; Sparrow, 1974) although there are interesting discrepancies according to species (Taylor, 1974). Unlike bean aphid, alatae of cereal aphids seemingly continue to colonise crops for much of the summer and, in the crop, the apterae may disperse widely but not uniformly from the original foci of infestation (Dean & Luuring, 1970; Dean, 1973). Weather conditions in June can notably affect aphid multiplication within the crop and so be an important factor influencing damage (Sparrow, 1974). Striking field-to-field variation in aphid populations, even between similar adjacent fields (George, 1974) may be caused by little understood effects of crop conditions on population increase as well as by differing numbers of immigrant colonists. Moreover, the complex of different aphid species with differing habits (Kolbe, 1969; George, 1974) and the nature of the damage to yield and quality caused partly by transmitted viruses, partly by foliar feeding but predominantly by feeding at a critical time on the developing 'ear' (Kolbe, 1968, 1970; Kolbe & Linke, 1974) add further to the difficulty of usefully forecasting need for and timing of insecticide applications. Kolbe (1970) and Kolbe & Linke (1974) make recommendations for immediate aphicide treatment if aphid numbers reach a critical level of about twenty per stem at the time of flowering though Kolbe (1970) indicates that even such last-minute decision making may not increase yield if, as can happen, aphid numbers then decrease naturally.

The apparently increasing importance of cereal aphids (George, 1974) and the prospect of widespread chemical control measures on the approximately nine million acres of cereals in Britain has extremely serious implications (e.g. Potts & Vickerman, 1974). Undoubtedly the most important present day need in agricultural entomology in Britain is to improve relevant knowledge of cereal aphid bionomics at least to the level of understanding that we have for species like bean aphid and peach-potato aphid.

The hop-damson aphid (Phorodon humuli)

This overwinters as eggs on Prunus spp. and so, like bean aphid, is probably little affected by variations in winter weather. Numbers of eggs should, therefore, indicate outbreak potential, but the situation is much complicated by notable variation in duration of the migratory period. This seems to be because production of alate migrants is influenced by the physiological state of the winter host (Kriz, 1966) rather than by crowding effects. Thus migration to hops may be prolonged by conditions which maintain vegetative growth of the overwintering host. Such variation in duration of the migratory period complicates rational decision-making on timing and frequency of insecticide applications though, in some circumstances, natural enemies may successfully control later colonists following a single well timed early application of a suitable insecticide (D.S. Madge, priv.comm.). Like cereal aphids, but unlike bean aphid and peach-potato aphid, there seems to be little relationship between the numbers of immigrants and the ultimate damage, which depends predominantly on conditions affecting multiplication and dispersion of apterous aphids after they have arrived on the crop (D.S. Madge, priv.comm.).

Table 4 summarises what is known of the relevant qualities of the different crop aphid species and shows that, in terms of present knowledge, long-term forecasting seems exceptionally favourable for the black bean aphid. Aphids which are pests of the primary host, such as the peach-potato aphid on peach and some aphids attacking apples, can, like bean aphid, be forecast from counts of oviparae in autumn or of overwintering eggs (e.g. Anon, 1973). Dr. G.H.L. Dicker (priv.comm.) points, however, to interesting biological differences which affect precision in forecasting abundance of the two most common apple-aphids. The numbers of the oat-apple aphid, (Rhopalosiphum insertum), developing in early summer can effectively reflect the forecast; the aphid multiplies for about two generations on apple, the second generation consisting almost entirely of alatae which migrate to grasses. In contrast, populations of the rosy apple aphid, (Dysaphis plantaginea), may remain for many generations on apple, producing alatae which may re-colonise it. Population increase, seemingly like that of the cereal aphids, depends on many factors that affect survival and multiplication in summer and so can be poorly related to initial numbers in spring and hence inadequately related to a forecast based on numbers in the previous autumn or winter.

DISCUSSION

At present the forecasting work on black bean aphid is based on sample counts of eggs in December or January, supplemented by counts of the active stages at peak population which occurs towards the end of May. The latter procedure is not discussed in this paper but it has confirmed conclusions based on egg counts and has occasionally given an improved forecast. However, it involves extra work at a busy time of the year for advisory entomologists and must be done in a limited time period and at a late stage close to the time when control measures are needed. Its main function is predicting the time of main migration from spindle and hence the optimum time for insecticide application. Such predictions need be based on the examination of only a few key spindle bushes in each 'area'. In contrast, egg sampling can be

Table 4. Characteristics of crop aphid species and current state of knowledge which influence possibilities of forecasting need for and timing of chemical control

Crops	Pest species	Nature of pre-crop habitat	Effect of winter weather on survival	Duration of main migration to crop	Relation between 'Rothamsted' trap catches & numbers of alatae colonising the crop	Relation between numbers colonising the crop & nos. in pre-crop habitat	Relation between numbers colonising the crop & ultimate crop damage	Earliest time when useful forecasts can begin to be made
Field beans Sugar beet	*Aphis fabae*	Localised (*E. europaeus*)	Relatively unimportant	About 3 weeks	Often positive	Positive	Positive	Sometimes in previous autumn; usually previous Dec./Jan.
Sugar beet	*Myzus persicae*	Common (Many different plant spp.)	Important	Up to about 7 wks. (in terms of virus spread)	May prove helpful but few trapped	Usually positive	Usually positive	Sometimes in winter or late spring; usually immediately after arrival on crop in mid-May/early June
Cereals	*Sitobion avenae* *Metapolophium dirhodum*	Common (grasses, winter cereals, Rosaceae)	Probably important though varying according to species	?	Little or none but essential bionomic data lacking	Not known	Seemingly at best inconsistent	Often not until flowering time
Hops	*Phorodon humuli*	Localised (*Prunus* spp.)	Relatively unimportant	5-8 weeks	Seemingly positive	Not known	Unknown (complexity due to variation in duration of migration)	In May on *Prunus* spp. usually after multiplication has begun on the crop.

spread over about two months in winter and the data can be collated and circulated by the Ministry's Advisory Service in early February - a useful four months before the time for insecticide application.

Present evidence indicates the following as a procedure for decision-making on control of the black bean aphid on spring-sown field beans. It does not apply to autumn-sown crops which are rarely harmed by the aphid nor yet to anomalous areas (S. Downs, S. Essex, S. Somerset). Area forecasts of 'unlikely', 'possible' or 'probable' damage should be made for farmers by the ADAS in late winter or early spring. At the end of May another forecast will also indicate if and when the farmer should examine his crops for aphid colonists, and when, if needed, he should apply an appropriate insecticide. The timing of crop examination and insecticide application is important and may vary within the first three weeks of June according to season and region.

On receipt of an area forecast of 'probable' damage, the farmer could, without further checks, arrange to apply the insecticide at the correct time. On receipt of a forecast of 'possible', he should delay the final decision until he has examined the crop. This should be done at the recommended time by checking the proportion of stems colonised on the south west or south edge of the field, preferably in the lee of a hedge or other wind-break, about 2-4 times the height of the hedge in from the edge of the field (Lewis, 1969). Insecticide treatment is unlikely to be needed if the examination indicates that less than 5% of stems are infested at this time. If more than 5% are infested, the farmer should examine samples of stems at intervals along one or two diagonal transects across the field. These will indicate whether all, or only the field edges, will need treatment. In some years, when the forecast of 'unlikely' is based on very scarce overwintering eggs, the farmer can be told that insecticide application will not be needed. Otherwise, especially when the forecast figure is just below the 'unlikely' to 'possible' threshold, the farmer should be advised to check as for a forecast of 'possible'. It seems that few farmers are nowadays prepared to adopt such procedures, but those who normally apply an insecticide as a routine might well be asked whether perhaps a few minutes examination would not be worth a saving of more than £150 on a fifty acre field, if this meant that treatment proved unnecessary. Farmers who delay insecticide application until they can clearly see bean aphid colonies on the bean stems could be saving very much more by adopting the procedure.

Work in parts of the European mainland as well as in England (Jones & Dunning, 1969; Way, 1967) indicates that populations of black bean aphids on crops tend to be large and small in alternate years (fig.5a). Although this has not been noticeable recently in many parts of southern England, the concept of a two-year cycle still provides an important basis for examining possible causes of the aberrations which, if understood, might then be compensated for in a long term forecasting scheme. The widespread use of insecticides, which stop expected outbreaks from developing, and the extensive use of herbicides which have made alternate and alternative weed hosts scarcer, may be comparatively recent factors that can alter the basic cycle in some areas (Way, 1967) but weather is undoubtedly important, as indicated by what seems to have happened recently in some southern areas of England. Many spring bean crops were very heavily colonised by bean aphid in June, 1973, so, on the basis of the two-year cycle, we predicted in July, 1973, that relatively small infestations would be expected in the year 1974 (as in fig.5a) unless the weather in August/September was unduly fine. This is because the aphids would be expected to become rare on weeds (notably *Chenopodium album*) in late August and September following the 'epidemic' in July. Few migrants would return to spindle in autumn and few would, therefore, migrate to crops in early June of the following year (fig.5a). However, above average fine weather in August/September seemingly prevents severe collapse of aphid populations in August and there can then be a notable increase in numbers on *C. album* if weather is fine in September (approx.

x 20 at Silwood Park, Berks., between Sept.4th - 30th, 1973) (fig.5b). In parts of southern England there has consequently been a large return migration to spindle in October, 1973, so potentially damaging infestations of spring bean crops are now expected there in the year 1974. Provisional predictions can, therefore, be made according to abundance of bean aphids on C. album in September. Furthermore, the numbers of alatae caught in some 'Rothamsted' suction traps from mid-September to mid-October seem to be correlated with black bean aphid abundance on local C. album as well as with subsequent abundance on local spindle. Therefore, the numbers of aphids on the bean crop in the previous June to July, the numbers on C. album in August to September, the catches of alatae by 'Rothamsted' suction traps from mid-September to early October, the numbers of oviparae in October, of eggs in December or January and of active stages in May, together provide a valuable sequence of data for forecasts. Several more years of results from all areas are, however, needed before the procedures can be properly tested and refined.

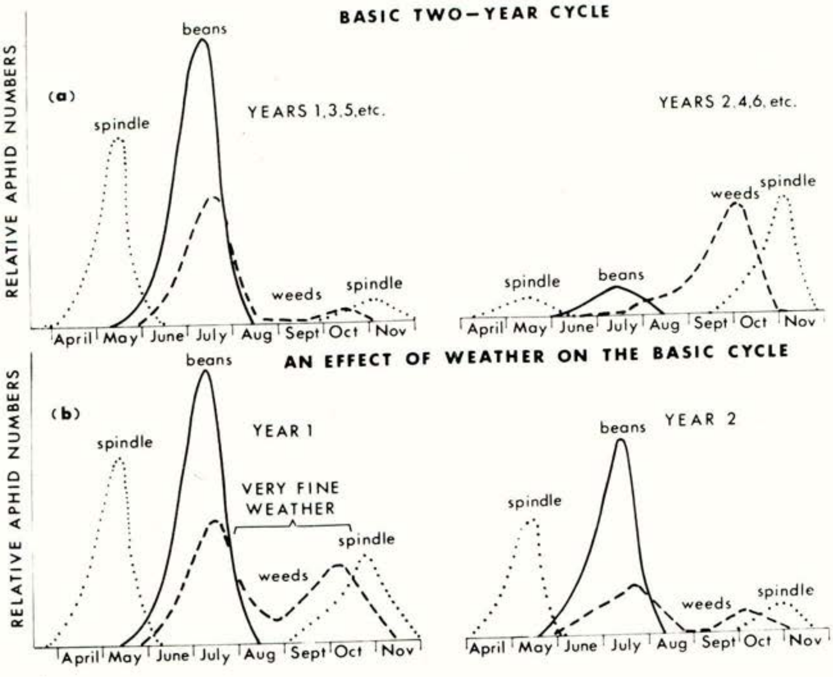

Fig.5 Diagrams of seasonal and annual changes in A. fabae populations on spindle, field beans and weeds. (a) basic cycle (b) populations in southern England showing effect of exceptionally fine late summer weather, as in year 1973, and possible pattern for 1974, assuming less favourable Aug. - Sept. weather.

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NEMATICIDES FOR TEMPERATE CROPS

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Summary In temperate soils many plant-parasitic nematodes harmful to field and glasshouse crops can be controlled by treating the soil with nematicides (soil fumigants, organophosphates and oximecarbamates). The most effective treatments not only prevent damage to crops but also minimise multiplication of the nematodes, so susceptible crops can be grown successfully more frequently in infested soil. Oximecarbamate nematicides (especially aldicarb and thioxamyl (Du Pont 1410) are little affected by soil composition and small amounts of them (0.5-10 kg a.i./ha) control cyst-, and root ecto-parasitic nematodes in the topsoil as well or better than large amounts of soil fumigants (100-600 kg or more/ha). Damage to crops by stem nematodes can be minimised by treating the crop rows with small amounts of aldicarb, thioxamyl or fenamiphos (Nemacur P) but multiplication of the nematodes may not be decreased.

Résumé Dans les terres tempérées on peut contrôler beaucoup des nématodes phytoparasitiques nuisibles à la récolte, soit en plein champ, soit dans les serres, au moyen du traitement des sols avec les nématicides (avec la fumigation des sols, les organophosphates et les oximécarbamates). Les traitements les plus efficaces sont capables non seulement de prévenir les dommages aux cultures, mais aussi de minimiser la multiplication des nématodes. Ainsi on peut plus fréquemment faire pousser avec succès les cultures susceptibles dans les sols infestés. Les nématicides oximécarbamates (surtout l'aldicarb et le thioxamyl) sont peu affectées par la composition du sol et on peut les utiliser à la surface de la terre a faibles doses (0,5-10 kg/ha) pour contrôler aussi bien ou même plus efficacement, les nématodes kystiques (*Heterodera* spp.) et ectoparasitiques aux racines (*Trichodorus* spp., *Longidorus* spp., *Xiphinema* spp.) qu'avec de grandes quantités des fumigants du sol (100-600 kg/ou plus/ha). Le traitement des rangs de la récolte avec de petites quantités d'aldicarb, de thioxamyl ou de Nemacur P peut minimiser les dommages aux récoltes par les nématodes des tiges (*Ditylenchus dipsaci*) mais un tel traitement n'est pas capable d'assurer la diminution de la multiplication des nématodes.

INTRODUCTION

This paper gives a brief account of nematicides for field and glasshouse crops, the methods by which they are applied and their effects on important nematode pests. Chemotherapy of nematode-infested planting material is not considered.

TYPES OF NEMATICIDE

Four groups of pesticides include nematicides suitable for temperate soils:- (i) halogenated aliphatic hydrocarbons- D-D, Telone (1,3-dichloropropene mixtures) in field soils and methyl bromide, ethylene dibromide and 1,2-dibromo-3-chloropropane in glasshouse soils, (ii) methyl isothiocyanate mixtures (Trapex (20% in xylol), Di Trapex CP (20% in D-D with added chloropicrin)) and precursor compounds (dazomet, metham-sodium), (iii) organophosphates, especially diethyl phosphorothioates and fenamiphos (proposed name for O-ethyl-O-(3-methyl-4-methyl-thiophenyl)-isopropylamido-phosphate) and (iv) oximecarbamates (especially aldicarb and thioxamyl (proposed name for methyl N, N-dimethyl-N-[(methylcarbamoyl)oxy]-1-thiooxamimidate). Compounds in groups (i) and (ii) act as soil fumigants, compounds in groups (iii) and (iv) have much smaller vapour pressures and exert little fumigant action on the soil. None of these nematicides is very persistent in soil.

Soil fumigants. Soil fumigants have some advantages over other nematicides. They kill many different soil animals simultaneously, including nematodes and their eggs. They can also kill nematodes deep in the soil and, except for methyl bromide and chloropicrin, are only moderately toxic to man and other vertebrates. Soil fumigants inhibit nitrifying bacteria which convert soil ammonium nitrogen to nitrate nitrogen. This is an advantage for crops in sandy soils from which ammonium nitrogen is less readily leached than nitrate nitrogen. Some fumigants (methyl bromide, chloropicrin and dazomet) also inhibit soil fungi and may kill or delay germination of weed seeds. Soil fumigants also have disadvantages in use. Large amounts are needed to kill most of the nematodes in soil (100-600 or more kg/ha). Except for dazomet, which is rotavated into the topsoil, they usually escape too rapidly from the soil to kill many nematodes near its surface. Nearly all are phytotoxic and must be injected several days, weeks or months before planting, but dibromochloropropane can be applied around the roots of woody perennials. Most soil fumigants are not so effective in soils containing much organic matter or clay or very wet or very dry soils. Harvested crops may contain appreciable soil fumigant residues (e.g. bromine after fumigation of some soils with methyl bromide or ethylene dibromide). In spite of these drawbacks soil fumigants are still used for nematode control, especially in warm soils containing little clay or organic matter.

Organophosphates and oximecarbamates. Organophosphates and oximecarbamates have little effect on nematode eggs but, being inhibitors of cholinesterase, act as nerve poisons on hatched nematodes, paralysing them in the soil, or repelling them from treated roots or shoots. They are very toxic to vertebrates as well as to invertebrates but have little effect on the soil flora. Much smaller amounts of these nematicides (0.5-10 kg/ha) than of soil fumigants are needed to immobilise nematodes in soil and they are not usually toxic to plants, so they can be applied at or just before planting. Soil composition usually affects the toxicity of organophosphates to nematodes but has less effect on oximecarbamates. The residues of oximecarbamate or organophosphate nematicides found in harvested crops grown in treated soils are very small.

APPLICATION OF NEMATICIDES

Efficient use of a nematicide requires it to be thoroughly mixed with the layer of soil in which it is to control nematodes. In glasshouses, methyl bromide is applied under polythene sheeting spread over the soil, the gas being fed in through delivery pipes from inside or outside the glasshouse. Liquid soil fumigants (1,3-dichloropropene, ethylene dibromide, dibromochloropropane and chloropicrin) can be injected into the soil from a constant-head gravity-feed dispenser but variation in forward speed of the tractor results in uneven dosage. A landwheel-driven pump (e.g. 'John Blue' fumigant pump) ensures even dosage. Liquid fumigants can be applied under the ploughsole during ploughing or through blade coulters mounted, usually 25-30 cm apart, on a tractor-drawn toolbar. The slits left in the soil by blade coulters must be sealed immediately and the soil surface harrowed to a fine tilth.

Nematicide granules should be as small as possible, flow easily, be non-dusty and very toxic ones should be unattractive to wildlife. Dazomet and other granular nematicides are evenly applied to the soil surface by a 'Sisag-Lospred' fertiliser distributor, provided it is shielded from wind. 'Horstine Farmery' microband granule applicators are also suitable but dazomet prill has proved unstable in such a machine, the fine powder to which some granules were ground sticking in and filling the grooves in the delivery wheels. Granules are better incorporated in soil by rotavating it to 15 cm depth than by a modified power harrow ('Roterra'). Rotavation of the soil to 15 cm depth ensures fairly even incorporation of granules to 15 cm deep (R.H. Bromilow, personal communication). To ensure that all granules are incorporated the applicator should be mounted in front of the rotavator. Foliar application of the oximecarbamate thioxamyl is hazardous and much less effective against nematodes than the same amount applied as granules to the soil.

Nematodes can be killed or immobilised deep in the soil by deep injection of soil fumigants or by ploughing dazomet or another granular nematicide deeply into the soil.

Nematode damage is more harmful to seedlings than to older plants and treating with nematicides only the crop rows at or before sowing seeds in them can reduce the damage more cheaply than treating all the topsoil.

Packaging, labelling and storage of nematicides need improving as well as the training of operators in the field. Improvements in protective clothing are also desirable.

NEMATODE PESTS IN TEMPERATE SOILS

The principal nematode pests are (i) cyst-nematodes (*Heterodera* spp.), (ii) stem nematodes (*Ditylenchus dipsaci*), (iii) root-lesion nematodes (*Pratylenchus* spp.) and (iv) in warm soils, root-knot nematodes (*Meloidogyne* spp.), and (v) stubby-root, dagger and needle nematodes, respectively, *Trichodorus* spp., *Xiphinema* spp. and *Longidorus* spp. which transmit some plant viruses. The first four groups are endoparasites and the last contains ectoparasites. Except for cyst-nematodes, all these nematodes can feed and multiply on many different plants in different plant families. Cyst-nematodes have narrower host ranges, usually limited to plants in one family but the beet cyst-nematode (*H. schachtii*) can multiply on plants of several families. Cyst-nematodes can be controlled by limiting the frequency of susceptible crops in the rotation as well as by using nematicides but crop rotation is usually ineffective against other species.

CONTROL

Killing three quarters of the nematodes in the soil usually prevents appreciable injury to susceptible crops and may greatly increase yields but, unless the nematodes have a small rate of multiplication on the host crops (e.g. less than fourfold), numbers may increase greatly and the soil will be more heavily infested after harvest than before planting. A nematode is fully controlled, only when a host crop can be grown profitably in infested soil, without increasing the number of nematodes left in the soil after harvest. If multiplication of the nematode is lessened partial control is achieved. The percentage of nematodes which must be killed or immobilised for full control is $100-\frac{100}{x}$, where x is the crude multiplication rate e.g. 90% for stubby-root, needle and dagger nematodes (up to 10-fold multiplication), 98% for cyst-nematodes (up to 50-fold) and 99.9% for stem and root-knot nematodes (up to 1000-fold).

Ectoparasitic nematodes. Large amounts of methyl bromide, D-D or chloropicrin (450-900 kg or more/ha) injected into soil may kill nearly all stubby-root, needle or dagger nematodes but such treatments are only justified for the control of certain nematode-transmitted viruses (e.g. arabis mosaic in strawberries transmitted by a dagger nematode (*Xiphinema diversicaudatum*)), when almost all viruliferous nematodes (approaching 100%) must be killed. The direct damage inflicted by the feeding of stubby-root and needle nematodes on the roots of sugar-beet seedlings in sandy soil in England (Docking disorder) is severe and results in much crop loss in affected fields only in years with frequent abundant rain in May and early June (Jones et al., 1969). The annual cost of controlling nematode damage must, therefore, be small. About 85% of the nematodes are killed when 45 l of Telone or 67 l D-D/ha are injected 15 cm deep in the rows in which sugar-beet seed is sown one to ten days later. Similarly, aldicarb granules at about 0.6 kg a.i./ha applied in the seed furrow during sowing prevent the nematodes feeding on the roots of the seedlings (and also control other seedling pests). These row treatments prevent serious injury to the seedling root systems, so serious yield losses are avoided (Whitehead et al., 1971).

Cyst-nematodes. Cyst-nematodes can be very damaging pests in temperate soils. For example, yield losses can exceed 30t potatoes or 25t sugar-beet/ha, in soil heavily infested with potato or beet cyst-nematodes. In different soils the average slopes of the quadratic regression lines relating potato yield with numbers of potato cyst-nematodes in potato roots differ considerably. Yield loss therefore depends on soil conditions as well as on the abundance of cyst-nematodes. Yield losses are increased by summer drought. Whitehead (1975) reviewed chemical control of cyst-nematodes. Recent experiments in England have shown that cereal cyst-, pea cyst-, potato cyst-, and beet cyst-nematodes can be fully or partially controlled by treating the topsoil with certain nematicides (Table 1).

Table 1. Control of four cyst-nematodes by oximecarbamates and organophosphates.

Treatment	kg a.i./ha+	Cereal cyst-nematode Barley grain (85% d.m.) (t/ha)	C.M.*	Pea cyst-nematode Fresh peas (t/ha)	C.M.
Untreated	0	2.3	X0.8	2.6	X0.9
Aldicarb	2.8	3.5***	X0.2	7.9***	X0.6
	5.6	2.6	X0.2	9.3***	X0.7
	11.2	3.4***	X0.1	9.1***	X0.5
Thioxamyl	2.8	2.8	X0.3	5.2***	X0.9
	5.6	2.9*	X0.2	6.8***	X0.7
	11.2	3.2**	X0.2	9.7***	X0.5
Dowco 275	2.8	2.4	X0.3	5.1***	X0.6
	5.6	2.6	X0.3	6.6***	X0.4
	11.2	3.0*	X0.2	7.4***	X0.4
		Beet cyst-nematode Sugar (t/ha)	**C.M.**	**Potato cyst-nematode Pentland Crown potatoes over 3.8 cm diam. (t/ha)**	**C.M.**
Untreated	0	3.4	X1.0	12.3	X2.0
Aldicarb	2.8	7.1***	X1.2	36.8***	X0.2
	5.6	7.7***	X0.6	33.8***	X0.1
	11.2	7.5***	X0.5	43.5***	X0.2
Thioxamyl	2.8	6.2***	X0.7	32.1***	X0.2
	5.6	7.0***	X1.8	34.9***	X0.2
	11.2	7.0***	X1.2	39.5***	X0.1
Dowco 275 (I)	2.8	3.3	X1.4	24.4***	X0.4
or	5.6	3.8 (I)	X1.7	26.2***	(II)X0.5
Fenamiphos (II)	11.2	6.2***	X1.1	27.7***	X0.3

+for control of cereal cyst-nematode the amounts used were 2.0, 5.6, 10.2 kg aldicarb a.i./ha and 2.4, 4.8, 9.6 kg thioxamyl or fenamiphos a.i./ha.

*crude multiplication rate, i.e. eggs/g soil after harvest divided by eggs/g soil before planting; calculated for cereal cyst-nematode from data supplied by Dr. T.D. Williams.

Potato cyst-nematodes were partially controlled on tomatoes in a heated glasshouse in Lancashire by treating the soil with 448 kg dazomet (dust or prill formulation)/ha and fully controlled by treating the soil with 448 kg dazomet and 448 kg Telone, 448 kg dazomet and 448 kg Di-Trapex CP, 1162 kg methyl bromide or 448 kg Di-Trapex CP and 11.2 kg a.i. thioxamyl/ha. Telone at about 448 kg/ha in closed containers of silty soil at a moisture equivalent to 200 cm water suction and a temperature of 21°C killed 99% of potato cyst-nematode eggs in one month. Much smaller percentages are killed in uncovered field soils where the gas escapes rapidly from the soil surface and much is adsorbed if they contain much clay or organic matter. Out-of-doors in uncovered sandy, silty and peat loam soils dazomet controls potato cyst-nematodes fully or partially when large amounts are thoroughly mixed with the topsoil. Good control can also be obtained by injecting Telone 25 cm deep in the soil to kill nematodes deep in the soil followed by incorporating dazomet in the top 15 cm soil to kill the nematodes near the surface (Whitehead, 1972; Whitehead, Tite, Fraser and French, 1973). The efficacy of 1,3-dichloropropene mixtures like D-D and Telone is affected far more by soil moisture than by soil temperature.

The oxime carbamate nematicides (aldicarb and thioxamyl) are little affected by soil composition and fully or partially control cyst-nematodes when incorporated in infested soil at 2-11 kg a.i./ha. (Table 1). Some organophosphates at 11 kg a.i./ha are similarly effective in different soils (e.g. fenamiphos and Dowco 275, a diethyl phosphorothioate).

Nematicides control cyst-nematodes much better when they are incorporated throughout the topsoil or the ridge than when they are applied in the seed furrow.

Stem nematodes. Stem nematodes cause 'bloat' disease in onions, 'tulip root' in oats, 'stem sickness' in clovers, 'crown rot' in sugar beet and 'brown ring' disease in flower bulbs. They are very difficult to control with nematicides because they can multiply up to 1000-fold on a susceptible plant, so they would only be fully controlled if up to 99.9% of them were killed or immobilised.

Large amounts of dazomet (672 or 896 kg/ha) incorporated in the topsoil kill about 96% of the nematodes (Duggan, 1971). Small amounts of aldicarb, thioxamyl or fenamiphos (1-11 kg a.i./ha) in the crop rows can protect seedlings from injury and greatly increase yields of a sensitive crop like onions in infested soil (Winfield, Murdoch and John, 1971; Whitehead, 1972). Treating onion rows with small amounts of oximecarbamates during sowing is better than incorporating the same amounts throughout the topsoil because stem nematodes affect only the shoots before and after emergence from the soil and row treatment concentrates the nematicide close to the plant. Surviving nematodes may multiply rapidly on the crop later in the growing season when temperatures decrease and moisture returns (Whitehead, Tite and Fraser, 1973). A second application of a systemic nematicide is needed to control this damaging phase of the attack.

INTEGRATED CONTROL

Monoculture is successful only if pests and diseases are fully controlled. Potato cyst-nematodes can be fully controlled in glasshouses by steaming or fumigating the soil every year before tomatoes are planted. In arable land cyst-nematodes can be fully controlled by treating the soil with nematicides, but, unless the host crop is sufficiently valuable, the amount needed may be too costly. If less nematicide is used the partial control achieved will suffice only if additional control measures are used i.e. crop rotation and or use of a resistant cultivar. Jones (1970) and Nollen and Mulder (1970) have shown how such integrated control of potato cyst-nematode can be achieved.

How effective a nematicide must be depends on what integrated control programme is used. The rate at which cyst-nematode numbers decline in soil is independent of the number of encysted eggs in the soil, and, for potato cyst-nematode, is usually about 33% per annum, for beet cyst-nematode about 40% each year. In some sand soils the decline rate may be faster, in some peat soils slower. The fraction of the population left after a number of years when no host crops are grown is shown in table 2, along with the equivalent crude multiplication rates. If susceptible potatoes are to be grown once in four years the nematodes must not be allowed to multiply more than about 3-fold on susceptible potatoes, if once in five years not more than 5-fold. If the soil is lightly infested potato cyst-nematode may increase perhaps up to fifty-fold on a susceptible crop so the nematicide would have to kill or immobilise up to 94% (3-fold multiplication) or 90% (5-fold multiplication) of the nematodes.

Table 2. Decline rates and equivalent crude multiplication rates for cyst-nematodes.

Years without host crop	33% decline rate		40% decline rate	
	% nematodes surviving (F)	Equivalent crude multiplication rate $\left(\frac{100}{F}\right)$	% nematodes surviving (F)	Equivalent crude multiplication rate $\left(\frac{100}{F}\right)$
0	100.0	X1.0	100.0	X1.0
1	66.6	X1.5	60.0	X1.7
2	44.4	X2.3	36.0	X2.8
3	29.6	X3.4	21.6	X4.6
4	19.8	X5.1	13.0	X7.7
5	13.2	X7.7	7.8	X12.9
6	8.8	X11.4	4.7	X21.4
7	5.9	X17.1	2.8	X35.7
8	3.9	X25.6	1.7	X58.8
9	2.6	X38.5		
10	1.7	X58.8		

If a resistant variety of crop can be included in the rotation a less effective nematicide treatment may be used, but if such a variety is planted in heavily infested soil it can be damaged as much as a susceptible variety and repeated planting may select a species or other pathotype able to multiply on it. Nematicides are therefore useful to prevent damage to resistant varieties as well as to prevent or lessen multiplication of resistance-breaking pathotypes or species of nematode.

There is every reason to suppose that use of effective nematicides will allow nematode-susceptible crops to be grown more frequently and more profitably in favoured temperate soils.

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NEMATICIDES IN TROPICAL AND SUB-TROPICAL CROPS

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Summary The "nematoses" or nematode induced diseases, of tropical crops are discussed in relation to their control by means of fumigant treatments and more recently introduced non-fumigant compounds, in particular prophos, fenamiphos and carbofuran. Methods of control, with rates of application and optimum times of treatment are given for the use of these compounds to control nematoses of banana, pineapple and citrus principally, and field experiments are described in which treatment has resulted in appreciable crop increase.

Résumé Les "nématoses", ou maladies causées par les nématodes, des cultures tropicales sont étudiées en rapport avec leur lutte au moyen de traitements fumigants et de composés non fumigants plus récemment mis au point, en particulier le prophos, fenamiphos et carbofuran. Les moyens de lutte, avec doses d'application et périodes de traitement optimales, sont indiqués pour l'emploi de ces composés contre les "nématoses" des bananiers, ananas et citrus principalement; des essais experimentaux, qui ont donné une augmentation de rendement des récoltes appréciable avec ces traitements, sont décrits.

INTRODUCTION

"Although much research in plant nematology has been conducted, nearly all of it has been done in temperate countries, whereas plant nematologists and appropriate research laboratories are insufficient or non existent in the humid tropics where plant nematodes and their damages are greatest". (extract from the introduction of Dr Chiarappa at the opening meeting of the Caribbean Symposium on Nematodes of Tropical Crops - Trinidad - April 1968) By these words, Dr Chiarappa gives a realistic picture of the situation of tropical nematology and subsequently makes us realise the relative limitation of the knowledge acquired on plant nematodes in warm climates. There has been very little improvement in the situation during the last five years.

It is easy to summarise the knowledge on the use of nematicides on tropical and subtropical crops, because there is very little literature on this subject. At the same time, this brings problems, because the information is very fragmentary and quite often inexact. What can be said on this subject?

First, we must talk about tropical agriculture, its aspects, consequences of the development of control methods against 'nematoses' (nematode diseases) then the new compounds with nematicidal activity, their properties which facilitate treatment. Then, lastly, information on tropical crops, their "nematoses" and the results of trials carried out using these new compounds will be given.

TROPICAL AGRICULTURE AND NEMATOLOGY

Traditional agriculture, under tropical conditions, is somewhat different from the agriculture in temperate countries. It is rather disparate and badly organised. On the same plot, mixed regional crops can be found - perennial species interplanted with annual species.

The small density of the same botanical species is unfavourable to the multiplication of nematodes. This type of cultivation is found close to the village, even around the huts. In other cases some cereals, like millet or mountain rice, are sown as single crops in one plot. The plot is different from one year to another, and includes a fallow period with growth of spontaneous vegetation. This practice is also not very favourable to nematode multiplication. Along the main rivers of West Africa, another cereal, sorghum, is sown every year on the same plots, but these are always flooded during the main rain season (for 2 to 3 months). There is no infestation of nematodes after this "natural cleaning".

All these crops are part-harvested as needed, and no effort to increase the yield is made. The use of nematicides on such a type of cultivation, used for all useful plants, is non existent and cannot be expected. But in developing countries and those with higher living standards, the agriculture is more rational, more technical, often organised by populations who came from other parts of the world, in former times or even recently.

This agriculture copies that of temperate countries in order to obtain higher yields. Single crop farming is often practised with rather important financial subsidies.

In this case, the constant cultivation of the same botanical species, with a density/ha. as high as possible, and farming methods allowing a good growth of perennial plants whatever the season, is very favourable to the multiplication of nematodes, in contrast to the conditions offered by traditional cultivation. These cultivation methods are not only used by companies or important landowners but, following their example, by local growers. They started to develop similar farms, with the creation of co-operatives or development associations financed by the State. Governments realised that extensive cultivation encouraged the development of the country and the social promotion of growers. There is no doubt that such an economic evolution will develop in all the countries where traditional methods prevailed for too long. But it is certain that in this favourable ecosystem, nematode infestations will become more and more important. Insects and plant diseases are in fact controlled by well-proven methods and large financial subsidies, but it is not yet the case for nematodes.

As soon as effective treatments are found, there is no reason why the same efforts should not apply to nematode control.

With this type of agriculture, the use of nematicides is not only possible, but necessary. If their application is still very limited, there is no doubt that it will increase in the near future with the joint development of this type of agriculture and tropical nematology.

As Dr Chiarappa pointed out, tropical nematology is very backward and once more we can only hope that the creation of well equipped laboratories, with specialised staff, will rapidly increase our knowledge. But even if the latter are still limited, one cannot say there is total ignorance. Studies and publications are becoming more and more numerous. Every day the importance of nematodes in tropical crops is emphasised.

We already know "nematoses" which kill the plant, such as "Red Ring" of coconut palm and "Spreading decline" of citrus. Control methods are not known but their spread can be limited.

For other "nematoses", such as the one caused by Radopholus similis in banana plantations, the improvement of control methods, only during recent years, allowed one to estimate the large losses caused by this nematode.

Some "nematoses" and their treatment methods are well known, but no control is carried out against them. This means that the growers do not realise the importance of these pests and of the losses they cause. Often, the relatively high cost of nematicidal treatments makes their recommendation only possible if the considered crop is profitable. Control methods will be used rapidly if they are effective and easy. So far, only fumigant nematicides are used and their application is difficult as they must be injected in the soil. The use of the soil injector itself is not very difficult, but treatment applications are very slow. The possible addition of some of these fumigant nematicides in irrigation water is already an improvement, but is still not enough for easy application. In addition, their mode of action is not very efficient, as the nematodes in the roots are not affected. They are quickly decomposed in the soil and have no persistence due to their high volatility, expecially in the high temperatures of the tropics. All these factors are unfavourable to quick development of the use of nematicides.

Now things have changed completely, with the introduction of new compounds, of low volatility and good persistence. They are formulated as granules which only need broadcasting on the soil. They are therefore much easier to use. They work systemically, their action is thus more dramatic and their efficiency is much higher than the fumigant nematicides. The conditions required for their efficiency are not so limited. This is a great advantage in the tropics, where weather conditions are often excessive, from one extreme to another, especially in respect of rainfall.

Although compounds presently available are already very effective, chemists will probably discover still better ones. The favourable characteristics of the new compounds should, in spite of their high cost (which will undoubtedly decrease), make highly effective nematicidal treatments possible. Their use in tropical countries should increase in the next few years, with the advancement of research work and the development of a rational and intensive agriculture.

NEMATICIDES AND THEIR METHODS OF APPLICATION IN TROPICAL COUNTRIES

Ethylene dibromide, D.D., and D.B.C.P. are the three most active fumigant nematicides so far used. The first two can only be used on bare soil before planting or sowing, due to their general phytotoxicity which is further increased by high temperatures in the tropics. Under such climatic conditions their persistence is very short due to their high volatility. D.B.C.P. is usually preferred. It is better tolerated by plants - its application even being possible during the growth stage - and its persistence is much longer due to its lower volatility. A soil temperature higher than 20° C is necessary to give a good diffusion of this nematicide. Furthermore, the existence of an e.c. formulation allows its addition to irrigation water.

This nematicide has been tested on many crops, often with very good results. It has given spectacular control of "nematosis" of banana to the extent that its use has become common in some countries. But the new compounds are even more interesting. I will not give here their physical or chemical characteristics, which can be found in other publications.

These new compounds are not fumigants. Their low volatility allows their granular application, the granules being mixed with the soil by mechanical action or buried deeply by rain water. These very simple treatments can be carried out easily by the local labourers who are not yet used to complex working methods. Their very simple application will make the treatments quicker, which is an advantage in tropical countries where weather conditions can change rapidly. Broadcast treatments can thus be made exactly during favourable periods. With their low volatility, a quick loss of action by vaporisation does not occur, even if the soil temperature is higher than 25 °C, which gives some persistence in the soil. If the soil temperature drops, their activity is not diminished so much. Their water solubility is low (some few hundred ppm). They will thus not be leached out during the rainy season and they can be applied without disadvantage during this period, which is very favourable to multiplication of nematodes. Broadcast treatments can be carried out at the most opportune times. This is a considerable advantage over fumigant nematicides, which can only be fully active if applied in a soil which is not too dry or too wet. In the Tropics, these conditions can be found only during very short periods which complicates control methods.

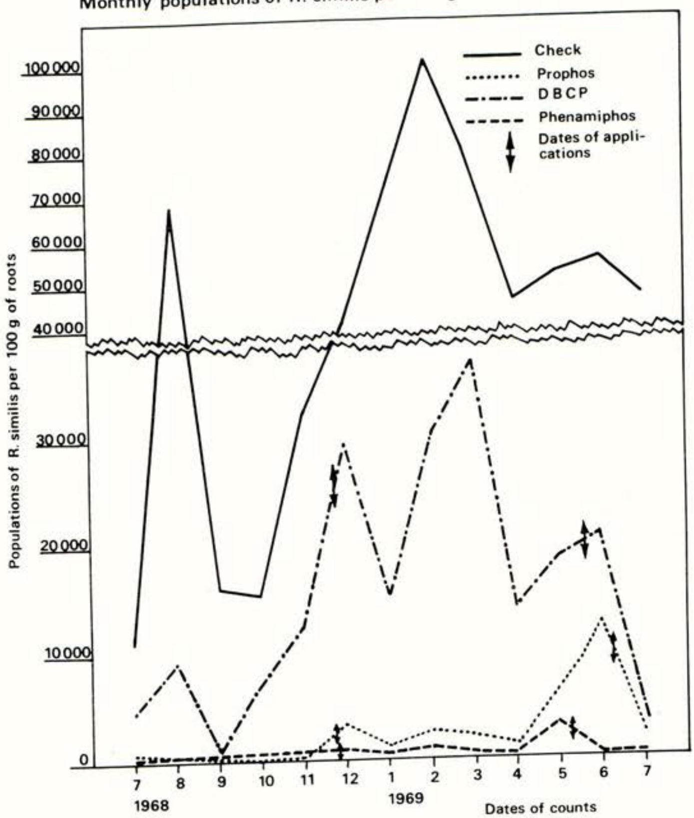
The new compounds are generally well tolerated by the various crops in the Tropics in spite of conditions predisposing to phytotoxicity, especially high temperature and strong sunshine. However it has sometimes been possible to detect an effect on plant development without any visible symptoms such as leaf discoloration or malformation, and only observations at harvest allowed one to record with certainty an inhibiting effect, not well documented because there can be at the same time growth retardation and stimulation. In addition, these effects are not always immediate but can appear after 12 or 18 months. But, at the usual rates, these effects are non existent or very limited and are not noticeable, being anyway compensated by the beneficial effects of the treatments.

The toxicity of these nematicides varies greatly; that of aldicarb is so high (LD_{50} = 0·9 mg/kg) that its use can be dangerous, especially when handled by the local labourers still little educated. It would be better to ban this nematicide altogether for any kind of crop in any country of the Third World.

The oral LD_{50} of the other nematicides is higher (8 to 14 mg/kg for carbofuran, 15 to 25 mg/kg for fenamiphos, 61 mg/kg for prophos) but still not inconsiderable. The use of granules considerably minimises the dangers and allows the use of these new compounds, but very simple precautions must still be observed. Prophos, carbofuran and fenamiphos are the three nematicides which appear to offer the best possibilities for use in tropical agriculture. The first acts by contact, the other two are systemic. They have been said to have "nematostatic" effects, that is to say they stop the biological cycle. But their action has not been really well defined. It is certain that some can have an action after absorption by the plant. They seem to prevent any new infestation or the development of the existing infestation. To the compounds already mentioned, must be added thioxamyl (DP1410), with systemic activity, which moves in the plant from the leaves to the roots. This should allow aerial spraying of the leaves, which would be a great convenience. Unfortunately, this compound is very quickly hydrolysed and its persistence is thus very short, which makes it lose much of its interest.

FIG. 1.

Monthly populations of R. similis per 100 g of roots.



NEW NEMATICIDES AND THE CONTROL OF TROPICAL "NEMATOSES"

After these few words on tropical agriculture and nematology, what are the possibilities for use of the new nematicides ?

Only the "nematoses" of typically tropical crops will be considered. An important section will cover the control of nematodes on banana, as this control is already a common practice in some countries. To our knowledge, it is the only one reaching this stage of development so far.

For other "nematoses", it has been proved many times that control methods were necessary, but little or nothing has been done in practice. For others, it is only possible to give some suggestions of treatment. We will only consider the new and most interesting compounds, which could be developed intensively in the near future. These compounds are carbofuran (Furadan), prophos (Mocap) and fenamiphos (Nemacur).

1. "Nematosis" of banana caused by Radopholus similis

R. similis is never found on its own but it is the most injurious species and the most difficult to control. The control of nematodes on banana resolves itself into the control of this species of worldwide distribution. Therefore the problem presents some uniformity at worldwide level.

Following trials carried out by the "Institut Français de Recherches Fruitieres Outre-mer, ou IFAC (French Institute of Overseas Fruit Research), treatments with DBCP have been recommended (Luc and Vilardebo, 1961).

Banana growers have become conscious of the importance of the problem and are now ready to use the new compounds available on the market. Fenamiphos and prophos, in April 1972 and May 1973 respectively have been given sales approval in France.

Carbofuran, last to appear on the nematicidal market, has already been given approval by the Commission Françaises de Toxiques. Its use in banana plantations will be allowed when results showing its effectiveness are ready.

Prophos and fenamiphos have been well studied by IFAC, as well as by other organisations. The knowledge acquired is already massive. But there is yet no publication concerning the use of carbofuran in banana plantations. It is possible to say that the first trials indicate similar effectiveness to that of fenamiphos.

1.1. Treatments in established banana plantations

Only granules with 5 or 10% of active ingredient have been used. In all treatments they were broadcast on the soil, without mechanical incorporation. Burying in the soil was caused by rain.

The results of the experiments carried out this way allowed one to estimate the effectiveness of these nematicides and to define appropriate methods of application.

1.1.1 Action on populations of R. similis

In figure 1, the curves of root populations indicate that a rate of 10 g of active ingredient/plant of fenamiphos or prophos, applied twice a year, is much more effective than the standard treatment with DBCP and the control is nearly total. This result has been clearly confirmed in all the other studies (Guérout - 1970; Vilardebo 1970; Vilardebo et al 1972, Melin and Vilardebo 1973.)

Table 1

Yield increases and increase of the average weight of banana bunches, following nematicidal treatments in some trials.

Country	Treatment	Yield 1st cycle in t/ha	Yield 2nd cycle in t/ha	Average weight of banana bunches 1st cycle in kg	Average weight of banana bunches 2nd cycle in kg
Ivory Coast	Control	21,7		17,3	
	DBCP	43,7		22,5	
	prophos(2x10g)	46,1		23,7	
	fenamiphos(2x10g)	52,3		26,8	
Ivory Coast	Control	24,5	9,0	16,8	12,2
	prophos(3x5g)	46,0	36,0	23,4	18,3
	fenamiphos(3x5g)	51,6	46,0	26,3	23,0
Western Cameroon	Control	30,7		19,1	
	DBCP	38,9		22,0	
	prophos (3x3g)	42,1		22,4	
	fenamiphos(3x3g)	46,4		23,5	
Costa Rica	Control	45		Increase of 25,4 to 37,2 kg during 10 months	
	prophos(2x6g)	56			
		During 10 months			
Surinam	Control	372 bunches of 12,7 kg average weight			
	fenamiphos	529 bunches of 14,5 kg average weight			

Considering all the trials, it has been estimated that the population levels below which R. similis had to be kept to avoid damage were 5000 and 10,000/100 g of roots in Ivory Coast and Cameroon respectively. A new compound is interesting only if it can establish or maintain this level.

This result is obtained with prophos and fenamiphos in the following conditions.

1.1.2 Frequency of application

It is apparent that the persistence of the compounds does not exceed 2 to 4 months and two annual treatments are insufficient. Experiments showed that 3 treatments/year represented the optimum frequency in Ivory Coast and Cameroon (Vilardebo et al 1972, Guerout 1973, Melin and Vilardebo 1973). Coates (1972), under Jamaican conditions, came to the same conclusion.

1.1.3 Application times

Broadcast treatments should be made at the beginning of periods of growth and again during the latter. These periods can be easily defined from the population curves.

The optimum periods are:

Ivory Coast	Cameroon
mid-April	beginning of April
end of July	beginning of July
beginning of November	mid-September

This aspect of the problem has apparently not been studied anywhere else.

1.1.4 Application rates

From the mass of results obtained with varied rates, those assuring the best control are the following:

	Ivory Coast	Cameroon
prophos	4,5g	3g
fenamiphos	3g	2g
carbofuran	3g	2g
(to be confirmed)		

These quantities /banana plant/ application are applied three times a year.

In Jamaica, 6g of fenamiphos in two applications does not give satisfactory results (Coates - 1972). In Surinam (Hasselbach, unpublished work), rates of 3 x 3g fenamiphos on very clayey soil gave good results. In the same conditions, prophos and aldicarb were ineffective.

In Central America, especially in Costa Rica, these new nematicides are used, according to the unpublished results of trials carried out by the production companies. We do not have detailed information. In Costa Rica, 2 applications/year of 4 to 6g of prophos gave very good results in areas where no nematicidal treatment had ever been used. In these countries rates of 3 to 5g of carbofuran/banana plant for each of the three annual applications are recommended.

1.1.5 Treated area per banana plant

Studies indicate that a treatment of 2 square metres is more effective, but for economical reasons, it is better to use only half the quantity of nematicide on 1 square metre, thus halving the treatment costs (Guérout, 1973).

Broadcasting of granules is done on a 40 cm diameter circle around the plant.

1.1.6 Increase of yield after treatment

In table 1, the figures give an idea of the increase of yield and the average weight of the bunches of bananas.

We do not need to discuss these results. They explain why nematicidal treatments have been used so rapidly in Africa and are now being developed in Central America.

1.2 Treatment of the planting material

The banana rhizome is infested with nematodes and treatment before planting presents a problem. The method of dipping in hot water is effective only under certain conditions, rarely met. Dipping in DBCP is not practicable, this compound being too phytotoxic. The properties of new compounds offer great scope in the treatment of planting material.

In Central America, it is recommended to dip the peeled stumps for 20 minutes in a 1000 ppm solution of prophos. Carbofuran is recommended at a similar rate (750 - 1000 ppm), but with a 10 minutes dipping time only.

In Jamaica, Coates (1971) considers that 5 minutes dipping in a 600 ppm solution of fenamiphos does not stop the growth recovery of un-peeled stumps, which are more resistant than peeled ones. Dipping in nematicidal mud has been tried successfully (Guérout, 1972). The mixtures obtained with clayey soils were subject to changes and it is preferable to use bentonite.

This must be put to swell in water (15 kg/100 litres) for 24 hours. The nematicide (e.c. solution or granules) is then added to give a concentration of 4000 ppm. The clean stumps, free of soil and roots but un-peeled, are dipped up to the crown, long enough to give complete cover of the surface. They are planted immediately; 28 to 30 cm diameter rhizomes can retain about 1 g of nematicide. The growth recovery is normal if the stumps, at the preblossom stage, are vigorous and at least 25 cm diameter. If the soil is free of nematodes, infestation by R. similis is practically non existent for 15 months after such treatment. But if the soil is already infested, invasion will start rapidly from this inoculum.

In this case soil treatment must be carried out without fail along with the plant treatment.

2. "Nematoses" of the pineapple

After bananas, it is probably on pineapple crops that nematicidal treatments are most developed. Treatment with DD is common practice in Hawaii for the control of Rotylenchulus reniformis and with DBCP against the same species in French Antilles and Pratylenchus brachyurus in Ivory Coast.

However control cannot be carried out as intensively as required, as treatments with fumigants cannot be repeated during the growth period.

With their very low phytotoxicity and mode of action, the new compounds offer great possibilities. Studies by Guérout (1973) in Ivory Coast can be summarised thus:

A few seconds dipping in a 1600 ppm solution of fenamiphos (but without removal of the suspension left in the centre of the plant) had an insufficient action. Better results have been obtained by application to the heart of the plant of 0·5g (granules or spray) of fenamiphos. Under these conditions prophos was less active, but if the compounds were broadcast on the soil the reverse was the case.

Whatever the method of treatment, carbofuran was as active as these two compounds. It appears to be the best nematicide for the control of Pratylenchus brachyurus.

Rates of 20 to 40 kg/ha of prophos, broadcast overall on the soil at planting time, control Rotylenchulus reniformis for 6 months. Yield increases of 10 to 25% are obtained for the first crop. With similar treatment methods fenamiphos, at a rate of 20 kg/ha, gives similar, if not better, results.

But for effective control of this nematode in the second crop or to control P. brachyurus during the first crop, treatments are absolutely essential during the growth period. These are either foliage sprays or granules broadcast into the heart of the plant (granules being dissolved by rain).

In Hawaii, two treatments of 10 kg each of fenamiphos sprayed in 10,000 litres of water/ha at 5 and 10 months, following a soil treatment with 20 kg of nematicide at planting time increased the yield from 49 to 65 tons/ha. In Ivory Coast, treatment at 2 and 4 months with 0·125 g/plant fenamiphos or furadan sprayed in 3000 litres of water/ha gave good results. Studies are continuing. These treatments are sometimes phytotoxic, especially with granular treatments or with prophos and if the weather is hot and dry.

In spite of these difficulties, the new compounds are an answer to nematode problems in pineapple. Effective, simple and economical treatments will be developed, without any doubt, in the near future. They will be applied by the growers.

3. "Nematoses" of Citrus

Among the various "nematoses" of citrus, two are especially important. One is caused by Radopholus similis and results in the death of the tree, the other is caused by Tylenchulus semipenetrans, much less harmful but found all over the world. It is more difficult to discuss the "nematosis" due to Pratylenchus coffeae, as it has been little studied.

O'Bannon and Taylor (1967) apparently published the first paper on the use of the new nematicides for the control of these "nematoses". Like O'Bannon and Tomerlin (1971), they studied the action of chemical dips on citrus saplings (roots or leaves). Dipping the roots, for 30 to 60 minutes, in a 1000 ppm solution of prophos or 250 ppm solution of fenamiphos gives 100% mortality of R. similis if the saplings are young. If older saplings are treated, the rates must be increased. Control of Tylenchulus semipenetrans is more difficult, the eggs and larvae being protected by an envelope of gelatinous substance. The activity of foliar sprays with fenamiphos indicates that this compound is translocated to the roots. Close examination of the results shows that the nematicide has a repellent or preventive action. These dips or sprays are strongly recommended for the treatment of young saplings coming from infested nurseries.

By brushing the trunk with a paste containing fenamiphos, Tarjan (1972) obtained a very large reduction in the infestation of Pratylenchus coffeae in the roots. This treatment method, simple and practical, is much safer for the workers than the foliar sprays.

Baines and Small (1969) studied the action of prophos, carbofuran and fenamiphos on Tylenchulus semipenetrans. These nematicides, applied at the rates of 50, 50 and 20 kg/ha of active ingredient respectively, were broadcast on the soil, then incorporated by irrigation water. After 4 months, nematode mortality was 70, 78 and 70%. These results, although poorer than those with a DBCP treatment (95%) perhaps do not represent the true effect. The systemic action of some of these nematicides may in fact have reduced the level of infestation of the roots better. In these short-term experiments, yield increase has not been studied. The yield increase, in an Indian plantation of sweet limes, was 39% in the second year, after treatment with prophos. (Mukhopadhyaya and Dalal, 1971). In Morocco, on clementine trees heavily infested with T. semipenetrans, Vilardebo and Squalli (1973) after treatments with prophos and fenamiphos for two years at the rates of 3 and 6 g/square metre on the whole area, obtained population decreases of about 80%.

There was no noticeable difference between the rates, and 3g/square metre appeared to be sufficient. There was no advantage in favour of either nematicide; however, fenamiphos seemed more persistent.

The average yield increase, for the whole of the treated plots, was 27%. The market value of this increase is higher than the treatment costs. These results show the importance of the control of this "nematosis". But the treatment methods with these new nematicides require further study. Direct brushing on the stem appears to be the easiest, safest and most economical treatment, while being highly effective. This new departure will certainly improve development of the control of citrus nematodes.

4. "Nematoses" of other crops

4.1 Coconut palm

There is actually no curative treatment with common fumigants for the Red Ring disease caused by Rhadinaphelenchus cocophilus. It was thought that compounds with systemic action might solve the problem. Hoyle (1971) found that fenamiphos injected into the stem was quickly inactivated after damaging the plant tissues, but was well absorbed by the plant if applied in the soil. But it is not sure that it can reach the nematode infested areas, the vascular canals being always blocked at the level of attack. Intensive studies are continuing.

4.2 Sugar cane

Among the many species infesting sugar cane, Tylenchorhynchus martini, Pratylenchus brachyurus and Trichodorus christiei are the most harmful. Nematicidal treatments are difficult, due to the large areas required for profitable cultivation and the characteristics of the crop. However trials have shown the benefit of control in Louisiana (Birchfield, 1969), Florida (Winchester, 1968) and elsewhere.

At planting time, the new compounds (granular formulation) should be broadcast in lines of 30 to 40 cm in the sugar cane planting rows, then covered with soil. This treatment is easy but later treatments are difficult in practice. It has been established however that 15 kg/ha of prophos or 8 kg/ha of carbofuran gave 35 to 40% increase of the sugar cane weight and 35 to 50% sugar content increase.

4.3 Cocoa

Tarjan, Jimenez and Soria (1971), following treatments in Costa Rica with prophos (33·6 kg/ha) or fenamiphos (22·4 kg/ha) broadcast round the trees in a 1·5 m radius circle, obtained for each nematicide compared with control crop weight increases of 20% and 96%. It appears to be the only information on control of nematodes on cocoa, in this case against *Hoplolaimus galeatus* and *Helicotylenchus erythrinae*.

4.4 Other crops

Preliminary studies, rather than experimental trials, have shown that the new compounds can control nematodes attacking other crops, especially cotton, peanut and coffee. It is not possible to give methods of treatment but simply to confirm that the new nematicides in these situations also offer real promise.

CONCLUSIONS

It appears that, in tropical countries, effective profitable and properly employed nematicidal treatments based on the new compounds are developed only for banana crops in several countries, and also on pineapple crops in Hawaii.

But the properties of the new compounds, especially their ability to work by contact or systemic activity, their persistence, ease of use and low phytotoxicity, in addition to the increasing information on tropical nematology, will allow the development of control treatments against the various "nematoses" uncontrolled by fumigant nematicides.

There is no doubt that these plant protection methods against nematodes will develop quickly and intensively for the benefit of agriculture and farmers in tropical areas.

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DEVELOPMENTS IN PEST AND DISEASE CONTROL IN HOPS

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Pest and disease control in hops is probably changing more rapidly at present than at any other time and probably more rapidly than in most other crops. This is due partly to new chemical treatments but also to the development of new varieties with high levels of resistance. It may seem inappropriate that this review paper at a pesticide and insecticide conference should be given by a plant breeder who is trying to make the use of pesticides and insecticides unnecessary. If this can be achieved it would be of considerable economic advantage to the hop grower as well as helping to reduce problems of pollution and taint in the brewery.

In spite of the attractions of resistant varieties, however, there is always the risk that resistance will break down. Nearly 20 years ago Professor Harland put forward the view that diseases were best controlled by the use of chemicals since fungal pathogens had the ability to develop strains which could overcome host resistance but not fungicides. Insects, on the other hand, could overcome chemicals but not host resistance so they should be controlled by breeding resistant varieties.

This theory, however, could not always be put into practice. No satisfactory chemical control of Verticillium wilt (*Verticillium albo-atrum*) has so far been developed and the hop industry has only survived in large areas of South-East England and of Germany through the discovery of resistant varieties. The absence of any varieties showing resistance to the damson-hop aphid has meant that this pest has had to be controlled by chemical means.

In both these cases, however, events have lent support to Harland's view. Hop aphids have quite definitely developed resistance to the main insecticide groups and there is some evidence that more virulent strains of *Verticillium* have also evolved.

Recent developments may favour the breeding of varieties resistant to disease. The new systemic fungicides which must, of necessity, be more specific in their toxic action than the old 'blunderbuss' chemicals may lead to the situation where fungi evolve chemical-resistant strains as effectively as insects, while plant breeders are becoming increasingly aware that some types of resistance mechanisms are less susceptible than others to strain differentiation by the pathogen. Unfortunately, there are no signs so far of new insecticides being developed which are not liable to be overtaken by genetic change in the insect they are intended to control.

The aspect of these new developments that I want to concentrate on to-day is the way in which they are liable to interact with one another. We already have good evidence in hop growing that such interactions have occurred and I would suggest that other cases will soon come to light.

Undoubtedly the most dramatic change in hop growing techniques has been the replacement of traditional cultivations by the use of herbicides. It was not long after this technique was adopted that powdery mildew (*Sphaerotheca macularis*) started to become a much more serious problem than it had been. Work by Royle & Liyanage has shown that the fungus has two methods of over-wintering which are both favoured by non-cultivation. Cleistocarps in infected plant tissue are left lying on the surface where the ascospores can be effectively released and powdery mildew mycelium can be found within the scales of buds at or near the soil surface which are left untouched under non-cultivation but would have been removed when cultivated gardens were dressed.

The increase in powdery mildew of recent years is not due solely to non-cultivation, however. For some years we have had circumstantial evidence that powdery mildew is more severe where zineb is used for downy mildew (Pseudoperonospora humuli) control than it is where copper compounds are used. Not until 1971, however, did we have experimental evidence to confirm this.

These two interactions are now well established but it has taken us a long time to accumulate the necessary evidence. I would suggest that we should all be looking for evidence of this sort of thing and should check it experimentally as soon as possible in order that growers may be warned of difficulties that they may run into.

The red spider mite (Tetranychus urticae) is a pest that seems to be staging a come-back especially in a hot dry year like this one. Some growers have commented this year that it is more difficult to control this pest in Wye Challenger than in other varieties. From what I could discover, however, I think this is not because this variety is any more susceptible but because it has not been sprayed against powdery mildew and so the acaricidal action of sulphur and dinocap has been lacking. If this is the case then one ought to be considering what the effect on spider mites will be of introducing pyrazophos for control of powdery mildew. Will its acaricidal action be more or less than that of dinocap against organo-phosphorus resistant mites?

Aphids have been a problem for the past ten years because of their developing resistance to insecticides. During this time we, at Wye, have been investigating two approaches to the problem. One is to determine how effective predators can be in controlling aphids and we have for several years shown that they can play a very important role during the latter part of the season. Clearly to benefit from their activity the insecticide programme must be planned so as not only to avoid killing them but also to actively encourage them by ensuring that there is something for them to feed on earlier in the season. We cannot yet recommend a programme which will guarantee control but undoubtedly it will be necessary to rely on soil drenches rather than foliar sprays. In case foliar sprays need to be used, however, it is important that their effect upon predators should be known. Our second approach to the aphid problem has been to look for resistant hops in a wide range of genetic material. For a long time we were unsuccessful but there are some indications of an important break through in this direction. We have plants which for two years have failed to support aphid development. Winged migrants of the damson hop aphid landed on these plants and produced nits on the young leaves of the shoot tips but the nits subsequently died out. Much work needs to be done on this material but it is exciting enough for one to speculate on the possible consequences. It could mean that varieties will appear which do not require to be sprayed against fungal diseases or aphids. What, I wonder, would be the effect of this freedom from chemical sprays upon spider mites? At worst they would be left with a perfect opportunity to become a major pest and we would be forced to develop spray programmes to deal specifically with them. It could happen, however, that the aphid colonies which would be produced throughout the migration period on the young leaves would not cause commercial damage to the hop plant but would support a predator population which would also be able to prevent the build up of damaging numbers of spider mites.

Finally I would like to show a few slides to demonstrate the effectiveness of resistant varieties. At the present time these provide much better control than can be guaranteed by chemical control methods. It is perhaps unfair that I can go ahead with these projects with confidence because I know that if resistance breaks down there is still chemical control to fall back on. Much more alarming to me is the thought that control of Verticillium wilt is entirely dependent upon plant resistance. The consequences of a new strain of wilt spreading through our hop gardens would be very serious and I still believe that it is highly important that a chemical control of this disease should be developed. I realise that as long as the plant breeder can keep the situation under control there is no economic incentive for the chemist to produce such materials. Those of us who are interested in the control of hop pests and diseases by breeding must hope, therefore, that breeders of other crops will be less successful so that there continues to be a market for a complete range of fungicides and pesticides on which we can fall back in time of need.

I do not think we shall hear much, during this session, about interactions such as I have mentioned. I would again make a plea, however, that when testing new chemicals, care should be taken to observe, and report upon, any interactions with other pests or diseases and, in the case of insecticides, that their effect upon predator species should be recorded.

Another side effect of chemical treatment may be that yield or alpha-acid content of the hops are affected directly and not as a consequence of pest or disease control. Here the plant breeder can, for once, help the chemist by providing resistant varieties on which such effects can be measured without any interference from the pathogen.