SESSION 8A

PEST AND DISEASE CONTROL IN HORTICULTURE IN RELATION TO QUALITY OF PRODUCE

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A RETAILER'S VIEW OF QUALITY OF HORTICULTURAL PRODUCT AND AGROCHEMICAL USAGE

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ABSTRACT

A recent survey showed that consumers place the quality of fresh fruit and vegetables high on their list of requirements when selecting where to shop. Safeway believe that this demand for quality is likely to increase, and has planned its buying and distribution system on this basis. There is a small but increasing demand for organically grown produce, to which Safeway is responding by buying UK-grown and imported vegetables and fruit. The price premium on organically grown produce is sufficient to provide a satisfactory return for the grower supplying it. A potential problem is the lack of a legally enforceable specification for organic produce in the UK, in contrast to many other countries.

INTRODUCTION

Before discussing some of my company's philosophies on the subject of quality and our attitude to the use of pesticides and fungicide in the production of crops, it is helpful to consider the scale on which this company operate. We have been operating in this country for 24 years. We now have 132 stores, trading from Dundee in Scotland to Bristol in the West and Canterbury in the East. By mid 1988 we will operate at least 150 stores and our sales in our last financial year exceeded £1 billion and profits were at record levels. We currently employ over 17,000 staff and have created over 1,400 new jobs in this year alone.

In the past three years as you leave a Safeways store, on the wall at the back of the checkouts is a message in large clear lettering, "SAFEWAY IS QUALITY AT LOW PRICES", not 'The best price in town', or 'Buy better at Safeway' or 'Compare our special offers' etc - just "QUALITY AT LOW PRICES". It is our corporate belief, not just a corporate theme. It's on all our advertising material. Is is our statement, our offering to the consumer, 'Quality at low prices', and if that offering is not correct, if it is not what the consumer requires, she'll walk away - shop elsewhere - and then we have no business left.

Todays consumers want quality products. They <u>demand</u> quality, and in a western world of increased affluence, the whole environment has become more quality orientated, clothes, home accessories, TV, fridges, dishwashers, videos, central heating, holidays, all because the consumers, the buyers, the users want and demand a better quality of life.

Three years ago we commissioned a housewife research project in a number of locations covering 2,500 households across all social classes. The object of this research was to discover the key factors that brought a customer into a Safeway store. In first place came convenience. The store was close to home, had convenient parking etc. In second place was the range of product stocked in all categories, this gives the consumer the choice of what product or variety to buy. And in joint third place with price came the quality of fresh fruit and vegetables. There were of course many other minor factors also - courtesy and friendliness of staff, clear and tidy stores etc - but now we have the key factors.

Bearing in mind that once you have built a store it is there for, you hope, at least twenty five years, there is not too much you can do on the convenience side. Maybe increase the size of the car park of the store, if adjoining land can be purchased, but what a challenge there is for the grower and the retailer - range and quality: he who gains a reputation for either or both should be secure for the next five or ten years, one hopes. But who knows what fickleness the consumer might show to either of these points. We have to continually monitor consumer trends, or we may find another retailer, grower or country has met the new requirement better than us. Regrettably, nothing is for ever in the fast changing consumer driven world of ours at the moment.

PRODUCING AND SUPPLYING QUALITY PRODUCE

Safeway, as part of its commitment to building a quality operation, decided many years ago that the only way to purchase considerable quantities of quality produce to the correct specification in all its branches, was to bypass traditional markets - go directly to growers and co-operatives and to operate a highly sophisticated infrastructure of qualified inspection at central distribution points, temperature controlled in warehouse and in distribution, in other words - centralised distribution.

Safeway now operate three major distribution depots, one in Aylesford on 52 acres, Warrington (Cheshire) on 30 acres and one in Glasgow, with a further major centre being planned to cope with our current growth by 1988.

We have led the way in central distribution but within the next 10 years it is my belief that all the major retailers will be operating in the same fashion. If this is the case, what will be the impact on growers of quality produce? Will they see increased returns or will they still be dependent on market trends? I do not have a crystal ball to answer this. What I will say is that as with the retailer, the quality of our offering is the only thing to bring our customers back to us again and again, and the price the consumer will pay will determine our returns. If she doesn't buy, none of us can sell. Even without the crystal ball I will guarantee you one thing - quality produce in the future will attract a greater premium than it does today. The future consumer will not accept poor quality from a major food retailer, nor will we from growers.

Now let us look more closely at how quality is perceived. Have we travelled blindly down the route of visual perfection at all costs? I think that to a certain extent we are guilty of this. As I said earlier we operate a sophisticated quality control on all produce coming to our distribution centres, but here at the point of intake the measurement we make on quality is primarily visual. On a delivery of Brussel Sprouts for example, we would expect the produce to be free from the following;

> Pests and disease; Pest or disease damage; Mould, slime or rot; Yellow or discoloured leaf; Elongated buds; Discoloured base leaves; Open buds; Side stalks; Overtrimmed or cut sprouts; A tired appearance; Extraneous matter; Frost damage or chiller damage; Chemical residues; Foreign smell or taste.

That list is quite a tall order for a product grown outside in the British climate, but it is generally met by our suppliers with the aid of chemicals to control pest and disease damage. When this item reaches our shops do our customers realise that this perfect sprout that they are going to eat has been sprayed possibly as many as three times with chemicals that are toxic at the time of spraying? Understandably the vast majority of our customers do not, but what of those that do wish to eat organically grown products. A few years ago these people would have been regarded as cranks - but that is not now the case. At Safeway we now sell a considerable amount of organically grown produce, far more than could be purchased by a few health food fanatics.

THE DEMAND FOR ORGANIC PRODUCE

Our first tentative steps into retailing organic produce were indeed very limited and fragmented; we honestly had no real idea of what we were getting involved in until customers started to telephone and write to us at head office and thank Safeway for giving them a choice.

We then started to receive contact from cancer clinics and skin allergy centres who had patients who required fresh produce which had to be absolutely clear of any agro-chemical residue, and real organically-grown fresh produce clearly met that criteria. Here was an area of development that was not foreseen by us, but obviously has tremendous commercial applications, plus the humanitarian benefits of being able to assist those less fortunate than ourselves.

Other reasons are varied, but include in the correspondence we have received: A sense of conservation awareness, a real belief that manufactured chemicals and sprays are being over-used and abused to the detriment of all of us.

Another reason given is flavour. To define flavour which is personal to each of us is indeed difficult, but without doubt the lack of flavour in the modern high-yielding, visually perfect, long shelf-life produce is well known to us all. Some organically grown fresh produce without doubt does seem to have improved flavour. But above all else, it does not matter what you or I think about organically-grown fresh produce; one person decides the fate of every single product being retailed in the high street every day, and it that is the customer, and I can assure you that customers are demanding this produce, be it for health reasons, a sense of conservation awareness, or simply something different, and are prepared to pay a premium to purchase their particular preference.

Interestingly, the customer profile is not just the A, B's and the more affluent areas we trade in, as you and I might expect, but does seem to generate across the whole profile, and even in the most price sensitive areas of high competition there is still a limited requirement for organically-grown produce.

PRODUCING AND SUPPLYING ORGANIC PRODUCE

Initially, the product range tended to be exotic type vegetables such as Kohl Rabi, Jerusalem Artichokes, Round Courgettes Mange Toutes, Petit Pois, Celeriac, Red Brussel Sprouts etc, in order to justify the extra value required to grow organically. However, as customer demand increased, our confidence improved, and we advised our growers to redirect their effort into normal mainstream products like potatoes, carrots, swedes, cabbage, lettuce and tomatoes, etc, where volume requirement levels were higher. The UK range now encompasses the whole basic range of commodities, root veg, green veg, salad, potatoes, top fruit.

As demand is constant throughout the year, we need to supplement the range with supplies from abroad and currently we are importing organically grown fresh produce from Holland, France, Italy, Spain and Israel. The current range available in early September in Safeway UK is as follows:

> Fresh Herbs, UK Savoy Cabbage, Dutch Red and White Cabbage, UK Potatoes and Dutch Potatoes, UK Carrots, UK Parsnips, UK Swedes, UK Khol Rabi, UK Beetroot, Israeli Avocados.

We expect to increase the range even further in the coming months, with Spanish Citrus and UK Apples in the next few weeks.

Gradually the product profile is increasing as suppliers at home and abroad realise that the UK is gradually responding to public demand as has happened in West Germany, Holland, France and the west coast of America.

If ever you need confirmation that we are discussing a growth industry, then let me tell you what Israel alone is doing. This year Israel will export into Europe 2,500 tons of product. This is backed by the Government with funds and technical support and whole Kibbutzs are being converted to the natural biological form of farming as the market expands.

The Israeli Government view the potential benefits to their agricultural industry as considerable, especially now that Spain and Portugal are in the EEC. Israel believes that organically grown fresh produce offers real potential, if they specialise and develop the business ahead of their competitors in Europe. The development of packaging, brand naming, and customer information is considerable. I believe that "Bio-Top" can be a brand leader just as Carmel and Jaffa are. In this industry, the Israelis are renowned for their ability to pick a winner, and really develop the business and maximise the potential while others watch and forever discuss the problems. Yet again they have achieved their objective.

One of the major points of discussion with growers who are considering converting to organically grown fresh produce or who have converted is the ratio of yield per acre, before and after convertion. Our experience to date is that for the first one or two years, there is undoubtably a definite shrinkage on yields against previous chemically-assisted crops.

Thereafter producers have built from this base level, and gradually increased their yields as the natural goodness in the soil begins to build up and pass on the residual benefit to the crops growing in this system. To date our growers have only increased their acreage as their confidence in the system and financial returns have been evaluated and compared. Our largest organic grower now farms approx 160 acres, and this has grown from an initial 30 acre development of vegetables.

On price premiums required we work on the following criteria: organically grown fresh produce requires a premium from the grower to survive and develop the business, our customers are prepared to pay an acceptable premium and no more. We base our price in relation to the alternative commercially grown product. If values are low we try and pay a

10-20 and even 30% premium, because the organic grower needs it to survive. The higher the value of any commodity, the less % premium an organic grower needs. In the end the price we agree with growers is based on trust, and I am well aware that if we do not pay enough, the supplier will go out of business. Likewise, if we pay too much, the product will not sell, so it is a delicate balance of reality and what premium we believe the product will stand at the sharp end of the business.

On pest damage, I must admit that I had severe reservations that pest problems would cause a severe shortfall of marketable produce. Surpriseingly though our suppliers do not seem to suffer from the white fly, aphid or botrytis problems that seem to beset the growing industry at times. Bearing in mind that the only spray most of the organic growers use is "Maxi crop", a natural seaweed product, it is amazing to me that problems do seem to be minimal, it's almost as if the plants build up a natural resistance to the major pest problems that occur throughout the year.

Of course, there are still problems as organic growers grapple with all the problems that the weather and mother nature throws at us, but to date we have not had a single producer who has lost a total crop or even more important, suffered financially.

On visual appearance, we were adamant that organically grown produce should not be an excuse for inferior produce, whilst aware that the appearance would not be the visual perfection we have all been seeking for regular produce. Neither should it mean poorly graded, badly presented produce, indeed much to the consternation of the organically grown produce industry we insist that product should be pre-packed, and clearly identified as organically grown. This served a two-fold objective; it disciplined the packing and presentation of the product, and it also enables us to identify to the customer that the product was unique. It also solved the marketing problem of a price premium requirement, hence our organic label and presentation.

On the visual appearance problem we have retrained our quality control inspectors to accept slight imperfections and mishapes which is the natural process. There is an acceptable level and an abuse level, all of our suppliers are clearly informed on product specification and presentation.

We have also explained this delicate problem in our organic leaflet which is given out in all stores to customers. Our overall objective is to aim for Class I produce and presentation, organic produce must never be an excuse for poor quality. This is not acceptable to us if we are to achieve the desired premium the producer needs.

THE DEFINITION OF ORGANICALLY GROWN PRODUCE

Legally what is organically grown produce? Here we have a unique situation, as yet there is no legislation for a UK-MAFF-ADAS definition that clearly defines to growers, retailers or the public what is organically grown produce. This situation is intolerable and deplorable, but above all else open for abuse at all levels. Criticism as to how and why such a situation could develop can only be levelled at those government agencies who have clearly failed to act. This may well be the intended policy of those concerned, and it is not for me to pass judgement.

Legally, therefore, we have a conundrum; there is a legal definition in France, Holland, Germany and Israel and recognition by the equivalent government agricultural related organisations.

Here is an industry that has evolved in the UK from consumer demand. That this industry has developed to such a large degree without the apparent support or acknowledgement of MAFF/ADAS amazes me. Why are we, a retail company having to advise growers on what they need to do to produce organically grown fresh produce, because they are unable to get the information from official channels?

HOW DO SAFEWAY DEFINE ORGANICALLY GROWN?

Safeway organically grown fresh produce is sourced exclusively from those growers who have been approved and passed as symbol-holders of the Soil Association, who have met the following criteria:-

1. All land must have been free from the application of artificial pesticides, herbicides, fungicides and other chemicals which may leave residues in the soil, for a period of 3-5 years. Although we live in a polluted world this ensures that any toxic residues left in the soil are at a minimum. Only naturally derived fertilizers made from fully composted materials are to be used, and produce grown without the assistance of any agro-chemical pesticides, herbicides or fungicides whatsoever.

2. Members must submit their land to soil analysis checks, product analysis checks and be prepared to accept frequent spot-check visits from Safeway Quality Control Technologists and buying staff in order to maintain the desired standards and codes of practice.

3. The farming system is to be operated as laid down by the Soil Association, being basically a biological system of farming that involves working with nature and natural products as much as possible, building up and maintaining the fertility of the soil through the interaction of micro--organisms in the soil, plants and animals.

Our concern is that although we have clearly defined, product wide and publicly, what is Safeway organically grown fresh produce, and linked this with the Soil Association, we are aware that at the present time any grower could market his produce as organically grown. Is he incorrect? He is by the way we define organics, but legally at present he is not guilty, unless he claims he has not used chemicals when he has.

We have justifiably earned a reputation as a company of integrity and high trading ethics, and that is why we guarantee with a label on each product that it is grown without the use of artificial chemical fertilisers on natural organic composts.

THE FUTURE FOR ORGANIC PRODUCE

The one question all of us would like an answer to is "How big will the organic market become and at what stage will it level out"? I am unable to answer that question, because to do so is pure speculation. I am not an organic evangelist, campaigning that organically grown fresh produce is the salvation to all our problems of over supply and fairly static demand, or that its growth potential is unlimited, because of course it is not.

The total retail fresh produce industry in the UK is worth £2 billion per annum, so even a small percentage figure for organically grown produce could be quite significant. I am not able to disclose our sales figures for organically grown fresh produce, but as I have indicated, is not an insignificant sum. We believe that a conservative figure could be around 2-4% of our total fresh produce business, and as the product group expands and availability increases, we believe a target figure at that stage of around 5-7% is not out of the question.

We see organically grown fresh produce as a viable product range alongside our existing business, never a replacement, but as a service for those customers who have a particular preference for this product group.

There is however one scenario that would make me change this view and lead me to forecast amazing growth in Organic Produce. This is if legislation was ever brought about, that at the point of sale we had to list what chemicals had been used in the production of a product. A typical label might read:-

FRESH POTATOES

(Contains residues of: Chlorpropham, Tecnazene,
Thiabendazole and 2-Aminobutane)

This does not make a pretty sight and certainly would do absolutely nothing to assist our sales. This may seem very far fetched and in truth I would agree with you, but I believe this example does highlight the very real danger of our customers, for whatever reason, believing that chemicals have been used to excess in the production of their food.

As I am sure you are aware, the Food & Environmental Protection Act is being enabled in 1987. This act of Parliament will set maximum limits for the residues of pesticides in food stuffs. How practical this is going to be for fresh produce remains to be seen, but I would certainly agree with the principle that there should be defined limits to pesticides residues. I do believe that chemicals are being used in excess by many growers, home and abroad and whilst I would not advocate that organic farming is necessarily the route to go, we are at Safeway encouraging all our growers to use a minimum input of chemical pesticides and fertilizers. We also encourage the investigation of any biological alternatives that may be available.

In the manufacturing industry companies are involved in reformulating many of their products in an attempt to make them as 'natural' as possible - such has been the bad publicity for 'E' numbers. The warning signs are clearly there. If we ignore this new consumer awareness that people are concerned about what they eat and are concerned about what has been done to the food that they eat, we do so at our own peril.

MEETING THE DEMAND FOR REDUCED INSECTICIDE USAGE IN THE PRODUCTION OF HIGH QUALITY FIELD VEGETABLES

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ABSTRACT

With increasing pressure now being placed on pesticide usage, systems of commercial crop production with decreased insecticide inputs are required. This paper describes research that has led to viable methods of decreasing insecticide usage and concludes that, although systems with reduced insecticide inputs are attainable, costs to the farmer and ultimate consumer will almost certainly increase.

INTRODUCTION

Control of insect pests on field vegetables in the UK has generally been so good since the introduction of the organochlorine insecticides that today's public now fails to appreciate the losses that would inevitably be sustained without the use of insecticides. To convince the similarly complacent Canadian public of its dependence on insecticides, Tolman *et al.* (1986) showed that, in the absence of any effort to control insect pests on potatoes, onions and swedes in S. Ontario, monetary returns for farmers fell below the cost of production of the crops. In the UK the severity of insect damage is likely to be equally extreme in the absence of insecticide treatments, especially on high value crops where the marketable units are damaged (Wheatley & Thompson, 1981).

The continuing need for the use of insecticides in food production in the UK was recognised in the Seventh Report of the Royal Commission on Environmental Pollution (Anon., 1979) and the protagonists of organic production have yet to demonstrate beyond reasonable doubt that planned, large scale commercial production of high quality field vegetables is feasible in the UK without some use of synthetic insecticides. However, pesticides are becoming an even greater focus of public concern and, as noted by Lester (1986), 'they continue to receive a measure of bad press out of proportion to their contribution to the overall problem of environmental pollution'. The need for more efficient insecticide usage is now more readily justifed in terms of protecting the quality of the environment than in terms of its monetary value to farmers. Research showing how reduced quantities of insecticides can be effective is described in this paper to illustrate the short- and long-term gains that can accrue from appropriate investment of resources.

SELECTION OF APPROPRIATE INSECTICIDES

A major goal of the search for new synthetic toxicants is to reduce the amounts of chemicals that have to be applied to crops to achieve the levels of protection demanded. The synthesis of the photostable, synthetic pyrethroid permethrin and its even more active successors (Davies, 1985), including the soil-acting tefluthrin (Jutsum et al., 1986), was timely. With recommended doses of pyrethroids for field application being measured in tens of grams of active ingredient per hectare in contrast to the kilogrammes used with most organophosphorus and carbamate insecticides, the dividends that can accrue from this type of research are self-evident. However, such breakthroughs have been infrequent in the history of insecticide discoveries and are likely to become even rarer. Reductions in the amounts of insecticides applied to field vegetables may also be achieved by stricter specifications of crop/insect targets. For example, reduced doses of the relatively persistent insecticides recommended for the protection of maincrop and overwintered carrots against carrot fly (Psila rosae) should be considered for treatment of short season carrots, to avoid unacceptable insecticide residues in harvested roots (Suett, 1986a).

The decreasing rate of introduction of new insecticides into world agriculture is reflected in the numbers that have become available, as spin-offs from usage on major crops, for 'minor use' on field vegetables. Thus, of the 22 candidate granular products evaluated against cabbage root fly (Delia radicum) and carrot fly at Wellesbourne since 1975, only two performed as well as the standard products and, of these, only one (carbosulfan) was subsequently commercialised. Although it is unlikely that novel active ingredients will be developed specifically for use on field vegetables in the UK, new formulations are more likely and some of these may reduce the overall need for insecticide usage. For example, the development of an improved strategy for control of cabbage aphid (Brevicoryne brassicae) on brassicas, based on the application of the systemic aphicide disulfoton to the soil at planting, with the subsequent demonstration of the compatability of disulfoton with insecticides applied to control cabbage root fly, prompted the commercial production by agrochemical companies of dual-component granular formulations likely to make unnecessary the application of several aphicidal sprays (Thompson & Suett, 1982). Season-long control of pests such as carrot fly in the soil still depends largely on relatively persistent insecticides applied at drilling. However, degradation of the insecticides together with declining soil temperatures in the autumn limits the performance of these insecticides late in the season (Wheatley & Thompson, 1981). Formulations which could be applied at drilling but which would not release the bulk of their active ingredient until the late summer when triggered by specific soil temperatures or moisture, for example, might reduce insecticide usage.

The development of resistance to insecticides by pests is a major factor limiting the numbers of products that can be applied on many world crops. Fortunately, resistance has not provided too many problems on field vegetables in the UK since the demise of the organochlorines. As yet, none of the major root-feeding species of Diptera has been shown unequivocably to be resistant to organophosphorus or carbamate insecticides, some of which replaced organochlorine compounds more than 20 years ago and are still used regularly. The early development of resistance to organophosphorus insecticides by the peach potato aphid (Myzus persicae) on sugar beet (Needham & Devonshire, 1975) warns against complacency but, in a reassuring recent study, no cabbage aphids from the 19 non-clonal populations tested survived the discriminating dose applied in laboratory tests (Furk & Roberts, 1985). However, an indication of phorate tolerance in a population of carrot fly from East Anglia (Thompson & Harris, 1982) suggests that the presence of a small proportion of less susceptible individuals may be at least partly responsible for difficulties with control of this pest. Recently, the accelerated degradation of insecticides applied to soil, induced by previous applications of the same or chemically similar insecticides, has been suggested as another factor at least partly responsible for the erratic performance of, especially, carbamate insecticides on field vegetables in the UK (Suett, 1986b).

APPLICATION METHODS

Although, over the last 50 years, application technology has not advanced at a rate commensurate with the dramatic increase in the potency of the chemicals being applied, some important advances have been made with demonstrable advantages in terms of improved 'dosage transfer'.

Sprayers are used extensively to apply insecticides to field vegetables. However, only small proportions of applied doses reach their targets, an unsatisfactory state of affairs providing a goal for cost-effective research. A survey in 1975 showed that differences of 100-150% between minimum and maximum nozzle outputs on the same boom were common and that mixing of different types of nozzle on the same boom was not unknown (Anon., 1976). It is essential that these results continue to stimulate the precise use of application equipment. Recent research in the laboratory confirmed that different droplet sizes are required for different types of target (Munthali & Scopes, 1982). A method of controlling droplet sizes within fairly narrow limits is by using centrifugal-energy nozzles (i.e. spinning discs or cups) but the importance of drop size to performance has not been missed by manufacturers of hydraulic nozzles. The current availability of readily switched nozzles on hydraulic sprayers offers a cheap means of improving spray deposition with a commensurate reduction in the application rate (Endacott, 1983). Further increases in the deposition of spray particles, particularly on the undersides of leaves, can be achieved by electrostatic charging of the spray droplets (Coffee, 1981). However, a disadvantage of electrostatic sprayers is the poor penetration of crop canopies and various methods, including air assistance, are being investigated to overcome this. In most climates, it is principally rain and dew that reduce spray residues so that the use of spray adjuvants which increase the rainfastness of foliar sprays inevitably decreases the need for repeated applications (Taylor & Matthews, 1986).

In the soil environment also, important advances have been made in the localisation of insecticide deposition. Knowledge of the routes of acquisition of insecticide doses by soil-inhabiting insects is almost non-existent. It is not known, for example, whether control of root-feeding species is achieved by contact, or stomach action, or both or even by fumigation. Increased knowledge of such factors would permit more rational approaches to insecticide placement. Twenty-five years ago, insecticide products were commonly broadcast over field soil. However, insecticide doses applied more than a few centimetres away from the plants are usually ineffective against the pests and may even benefit the pests by reducing their predators and parasites. Thus the confinement of products in continuous bands applied in or on the soil to plant rows with tractor-mounted equipment, the almost invariable practice nowadays, improves the efficiency of insecticides in terms of the level of control achieved per unit of active ingredient. However the results of a survey of granule applicators used on commercial brassica farms (Thompson et al., 1984) showed that inadequate setting up and calibration of the equipment often marred levels of efficiency. When plants are spaced well apart in the rows, even more precise placement of insecticide can be an even greater advantage, resulting in substantial savings of products. A machine designed by A.S. Orwin of the Pershore Horticultural College to deliver granular products only at plant positions gave control of cabbage root fly on transplanted Brussels sprouts with only 50% of the insecticide applied in a continuous band (Thompson & Percivall, 1978).

The development of machinery for applying insecticides to field-sown crops at drilling has lagged behind the advances made with the drills themselves. Thus, irrespective of the depth to which root-feeding insect larvae are known to feed on root vegetables, farmers until recently have had to rely mainly on equipment placing granular insecticide formulations, by techniques including the 'bow-wave' (Makepeace, 1965) and in-furrow methods, in the surface 2 cm of the soil. Only recently the configuration of the seeder coulter which causes the bow-wave was shown to affect the performance of these treatments, especially with relatively non-mobile insecticides applied to short-season crops (Thompson et al., 1982a). Results from experiments with insecticides incorporated in the gels used for drilling pre-germinated seeds has indicated that even more intimate contact of seedlings with insecticides improved the performance of the active ingredients against carrot fly on carrots (Thompson et al., 1982b). Possible advantages in terms of reduced insecticide usage may be gained by a similar system applying low volume liquid band treatments to field-sown seed with microtube sprayers. This offers very accurate dosing and reduced operator hazards (McCracken, 1986). In contrast to these shallow methods of insecticide placement, a commercial Vertical Band Applicator (Whitehead et al., 1981) which distributes granular formulations uniformly from the soil surface to a depth of c. 15 cm has increased the performance of insecticides against deep-feeding insect larvae (Thompson et al., 1986). Optimising insecticide placement in this way presents opportunities for adequate protection by reduced doses. At the same time it probably minimises some of the undesirable side-effects of insecticides on soil-living predators and thereby also assists in extending the period of commercial usefulness of insecticides.

The incorporation of insecticides into peat blocks used for raising transplants enables accurate doses to be applied to plants, irrespective of variable soil and weather conditions which can introduce large variations in plant-to-plant dosing with field treatments. The distribution of insecticide between individual blocks can be exceptionally uniform, more than 90% of blocks often containing within 10% of the target dose (Suett & Padbury, 1982). 'Approval' has been given by the MAFF Pesticides Registration Department for block-incorporation of some organophosphorus insecticides to protect brassicas against cabbage root fly (Saynor et al., 1986). However the trend towards smaller blocks and the use of loose-filled cells have left the plant-raiser with no option but to apply pesticide treatments to the module surface in order to avoid the risk of phytotoxicity from incorporated treatments (Saynor et al., 1986). It is regrettable that these surface treatments are often applied by procedures which are difficult to calibrate and a recent survey (Suett, 1986c) indicated that most applications to the surface of modules were inaccurate and highly variable. Doses in individual modules varied more than 10-fold in many samples. Although effective pest control can be achieved using, with module-raised plants, only 20-30% of the active ingredient needed with band treatments in the field, precise workable procedures are needed for the large scale commercial application of the treatments if these treatments are to remain viable.

Seed treatment offers an economical means of placing insecticides in the critical region to protect seeds and emerging seedlings from pests in the soil. Systemic insecticides can also be applied in this way to protect seedlings from insects feeding on crop foliage. Although much success was achieved using a liquid formulation of pirimiphos-ethyl to protect bean seedlings against the bean seed fly (Delia spp.) (Gould & Mayor, 1975), the commercial incentive for continued manufacture of this formulation was not adequate. This emphasises once again the tenuous nature of crop protection in the 'minor uses' sector. Major disadvantages of many seed treatments are their physical instability and large variations in doses from seed to seed. It is possible that overdosing of some seeds may have been responsible for the phytotoxicity observed with many organophosphorus insecticides. Initial studies of a film-coating process in which seeds are suspended in a fluidised bed during treatment (Horner, 1985) have shown that coefficients of variation of less than 20% were achieved between doses on individual seeds (Maude & Suett, 1986). Film-coat application of chlorfenvinphos to carrot seed controlled severe infestations of carrot fly 26 weeks after drilling with less than 20% of the insecticide applied by field treatments with granules (Thompson et al., 1983). Even further reductions in application rates were demonstrated in recent experiments in which high and also uniform insecticide concentrations were induced in radish seedlings in the laboratory prior to the seedlings being transplanted in the field (Suett & Whitfield, 1986). Levels of protection against cabbage root fly were similar to those provided by conventional band applications with granules in the field but were achieved using less than 3% of the amount of active ingredient.

PEST FORECASTING AND MONITORING

Accurate forecasting of the timing and intensity of erratic infestations of pests can provide a means of substantially reducing the frequency of insecticide applications, especially when the forecasts are related to robust action-thresholds. Long series of appropriate data are needed to establish general principles of pest insect distribution and abundance and to define criteria, including economic damage thresholds, on which rational pest control based on reliable warning systems can be adopted (Way et al., 1981). However, the benefits that can accrue from the eventual implementation of the forecasts justify the delayed returns from the financial investment.

A good example of a highly-developed system is that used for forecasting infestations of the black bean aphid (Aphis fabae) on spring-sown field beans. In eight years of a nine-year trial period, this system accurately forecast the need to spray on 90% of the occasions studied (Way et al., 1981). Advanced monitoring and forecasting systems are now available for many species of aphids, but few have threshold data and they are used mainly to avoid unnecessary application of insecticide treatments (Tatchell, 1982). Threshold catches of the pea moth (*Cydia nigricana*) in pheromone traps are now used extensively in the UK by ADAS officers for distinguishing crops of dry-harvested peas unlikely to suffer economic damage if control measures are not applied (Wall et al., 1986a) and recent experiments have been used to test similar systems in crops of vining peas. Thus, using an analogue of the pheromone used in traps in dry-harvested crops, Wall et al. (1986b) showed that, over a three year period, unnecessary spraying could have been avoided at 88% of the sites investigated. Systems for saving unnecessary insecticide applications by the supervised control of foliar pests of brassicas based on threshold numbers of insects have been described (Theunissen, 1984). However, the need for simple, economic and yet reliable crop sampling methods that are usable by farmers in the absence of trained and therefore costly 'scouts' remains (Wheatley, 1986). The use of models relating the development of 'cutworm' larvae of the turnip moth (*Agrotis segetum*) (Bowden et al., 1983) and of the cabbage root fly (Finch & Collier, 1986) to climatic parameters has indicated the advantages that are to be gained in terms of more accurately timed insecticide applications with these species also. Of the many crop/pest situations warranting intensive study with a view to increasing the efficiency of insecticide treatments, that of carrot fly on maincrop and overwintered carrots demands immediate attention. Rationalisation of the current commercial strategies based on two- or four-weekly sprays applied in mid-season and clearly leaving 'windows' for egg-laying and larval development by carrot fly would almost certainly result in reduced insecticide usage and, possibly, improved crop protection.

INTEGRATION OF CROP PROTECTION METHODS

There are many other methods of suppressing pest populations other than the use of insecticides. In isolation, none is likely to be adequately effective but in combination they may help to suppress pest populations sufficiently to enable reduced doses of insecticides to achieve required levels of effectiveness.

An area of research that has attracted considerable resources and which may contribute significantly is the breeding of crop plants for resistance to insect pests. The almost total resistance to lettuce root aphid (*Pemphigus bursarius*) of the lettuce cultivars Avoncrisp and Avondefiance (Dunn & Kempton, 1974) remains the most notable example of host-plant resistance in vegetables. However, degrees of resistance to lettuce root aphid that have subsequently been bred into other lettuce cultivars have sometimes been accompanied by unexpected drawbacks detracting from the crops' value, emphasising the need for new cultivars to be evaluated comprehensively before being marketed (Ellis, 1986). Significant progress has been made in the search for resistance in other crops, a prominent example being the partial resistance of some carrot cultivars to the carrot fly. Using cv. Sytan, a partially resistant cultivar, Thompson & Ellis (1979) showed that the contributions made towards carrot fly control by insecticidal and host-plant factors were complementary. They concluded that scope existed for the development of control programmes based on carrot material selected for partial resistance, and a reduced insecticide input. The benefits of combining levels of partial resistance with insecticide treatment to control cabbage root fly have also been demonstrated (Ellis _et al_., 1986b).

The combination of partial host-plant resistance with sowing dates designed to avoid periods of peak pest activity provided conditions under which satisfactory yields of marketable carrots could be obtained in a field where high populations of carrot fly existed (Ellis _et al_., 1986a). This sort of approach to the carrot fly problem should be compatible with more rational use of insecticides and would result in decreased use of insecticides. However, a truly integrated programme for the control of carrot fly could only be implemented if growers were prepared to alter cropping schedules. As with other instances in which alternative approaches to the use of insecticides were demonstrated to be effective (Harris _et al_., 1981), it is unlikely that integrated systems of carrot fly control could be implemented overnight.

GENERAL DISCUSSION

The commercial production of high quality field vegetables in the UK is vulnerable to any event which may precipitate perception of the use of insecticides as undesirable, however irrational that point of view may be. Strategic research to develop more diversified, practical systems of crop protection which would reduce this vulnerability is needed urgently. However, with alternative methods to insecticide usage generally requiring considerable lengths of time for development to large scale commercial use, short term emphasis is needed on environmentally-acceptable, robust methods with reduced insecticide inputs. Approaches discussed in this paper suggest that crop protection systems with reduced inputs, but inevitably not zero insecticide involvement if quality standards are to be maintained, are attainable. However, extensive use of such systems may have serious repurcussions if manufacturers and distributors of agrochemicals find markets are no longer large enough to support their products. Already, some products marketed only for 'minor uses' have become unavailable because the sales demand was inadequate. It seems likely that some products used in the horticultural sector will assume not only pharmaceutical doses but also pharmaceutical prices!

With the hastening of progress towards highly refined crop protection systems with integrated inputs from entomologists, plant pathologists and weeds specialists, as well as from those in research disciplines related to the agronomy of crop production, the demands on the technologically-based field vegetables industry to keep pace are increasing. Green (1974) remarked in the context of research that 'men capable of comprehending all of the components of crop protection systems are required'. The need already exists on farms. The immediate challenge for the field vegetables industry is to use all its available resources to promote more reasoned approaches to pest control so that agrochemicals may come to be used within systems which have increased stability and conserve all the resources of horticulture as a prime objective (Lovett, 1982). At present, the financial cost of implementing many systems of insect control as alternatives to the use of insecticides is likely to exceed that of conventional methods. The era in which we rely solely on insecticides to control many insect species may well be drawing to a close but, as Harris _et al_. (1981)

asked, will consumers be willing to pay higher food costs to allow for the increased cost of integrated pest management?

REFERENCES

Anon. (1976) The utilisation and performance of field crop sprayers. ADAS Farm Mechanisation Studies 29.

Anon. (1979) Seventh Report, Royal Commission on Environmental Pollution; Agriculture and Pollution. HMSO, London.

Bowden, J.; Cochrane, J.; Emmett, B.J.; Minall, T.E.; Sherlock, P.L. (1983) A survey of cutworm attacks in England and Wales, and a descriptive population model for Agrotis segetum (Lepidoptera: Noctuidae). Annals of Applied Biology 102, 29-47.

Coffee, R.A. (1981) Electrodynamic crop spraying. Outlook on Agriculture 10, 350-356.

Davies, J.H. (1985) The pyrethroids: an historical introduction. In: The pyrethroid insecticides (Ed. J.P.Leahey). Taylor & Francis, London. pp. 1-41.

Dunn, J.A.; Kempton, D.P.H. (1974) Lettuce root aphid control by means of plant resistance. Plant Pathology 23, 76-80.

Ellis, P.R. (1986) The role of plant resistance to pests in the provision of healthy planting material. British Crop Protection Council Monograph No. 33: Symposium on Healthy Planting Material, pp. 137-143.

Ellis, P.R.; Hardman, J.A.; Cole, R.A.; Phelps, K. (1986a) The complementary effects of plant resistance and the choice of sowing and harvest times in reducing carrot fly (Psila rosae) damage to carrots. Annals of Applied Biology (In press).

Ellis, P.R.; Hardman, J.A.; Thompson, A.R.; Mayne, H.J.; Saw, P.L. (1986b) Resistance of vegetables to insect pests: Brassicas. Report of the National Vegetable Research Station for 1985, p.29.

Endacott, C.J. (1983) Pesticide application in practice: slow adoption of new techniques. Span 26, 113-115.

Finch, S.; Collier, R.H. (1986) Forecasting the times of attack of the cabbage root fly (Delia radicum) on brassica crops. Aspects of Applied Biology 12.

Furk, C.; Roberts, H. (1985) Baseline responses of United Kingdom field populations of Macrosiphum euphorbiae (Thomas) and Brevicoryne brassicae (L.) (Hemiptera: Aphididae) to demeton-S-methyl. Bulletin of Entomological Research 75, 65-71.

Gould, H.J.; Mayor, J.G. (1975) Alternative seed treatments to dieldrin for the control of bean seed fly (Delia spp.). Plant Pathology 24, 245-246.

Green, M.B. (1974) Introduction to a session on the application of biological control. In: Biology in Pest and Disease Control (Eds. D. Price Jones and M.E. Solomon). Blackwell Scientific Publications, Oxford. pp. 357-358.

Harris, C.R.; Svec, H.J.; Tolman, J.H.; Tomlin, A.D.; McEwen, F.L. (1981) A rational integration of methods to control onion maggot in southwestern Ontario. Proceedings British Crop Protection Conference - Pests and Diseases 3, 789-799.

Hörner, E.L. (1985) SHR - a new technology for seed processing. International Agrophysics 1, 141-145.

Jutsum, A.R.; Gordon, R.F.S.; Ruscoe, C.N.E. (1986) Tefluthrin - a novel pyrethroid soil insecticide. Proceedings British Crop Protection Conference - Pests and Diseases.

Lester, E. (1986) Objectives and perspectives in plant disease control. *Plant Pathology* *35*, 2-14.

Lovett, J.V. (1982) Agro-chemical alternatives in a future agriculture. *Biological Agriculture and Horticulture* *1*, 15-27.

Makepeace, R.J. (1965) The application of granular pesticides. *Proceedings 3rd British Insecticide & Fungicide Conference* *1*, 389-395.

Maude, R.B.; Suett,D.L. (1986) Application of fungicide to brassica seeds using a film-coating technique. *Proceedings British Crop Protection Conference - Pests and Diseases*.

McCracken, A. (1986) A low-volume microtube in-furrow sprayer. *Proceedings 6th Pesticides, Formulations and Applications Symposium* (Florida) (In press).

Munthali, D.C.; Scopes, N.E.A. (1982) A technique for studying the biological efficiency of small droplets of pesticide solutions and a consideration of its implications. *Pesticide Science* *13*, 60-62.

Needham, P.H.; Devonshire, A.L. (1975) Resistance to some organophosphorus insecticides in field populations of *Myzus persicae* from sugar beet in 1974. *Pesticide Science* *6*, 547-551.

Saynor, M.; Lane, A.; Lole, M.; Watling, M.; Antill, D. (1986) Control of cabbage root fly with insecticides applied to peat blocks and loose-filled cells. *Aspects of Applied Biology* *12*.

Suett, D.L. (1986a) Insecticide residues in commercially grown quick-maturing carrots. *Food Additives & Contaminants* (In press).

Suett, D.L. (1986b) Accelerated degradation of carbofuran in previously treated field soils in the United Kingdom. *Crop Protection* *5*, 165-169.

Suett, D.L. (1986c) Accuracy and uniformity of insecticide treatments of commercially-produced plant propagation modules. *Crop Protection* (In press).

Suett, D.L.; Padbury, C.E. (1982) Incorporation and stability of chlorfenvinphos, chlorpyrifos, diazinon and phorate in peat blocks. *Pesticide Science* *13*, 229-245.

Suett, D.L.; Whitfield, C.E. (1986) The fate, distribution and biological performance of insecticide residues in vegetable crops following seedling treatment. *Annals of Applied Biology* *109*, 71-85.

Tatchell, G.M. (1982) Aphid monitoring and forecasting as an aid to decision making. *Proceedings British Crop Protection Council Symposium: Decision making in the practice of crop protection*, pp. 99-112.

Taylor, N.; Matthews, G.A. (1986) Effect of different adjuvants on the rainfastness of bendiocarb applied to Brussels sprout plants. *Crop Protection* *5*, 250-253.

Theunissen, J. (1984) Supervised pest control in cabbage crops: theory and practice. *Mitteilungen aus der Biologischen Bundesanstalt für Land- und Forstwirtschaft* *218*, 76-84.

Thompson, A.R.; Ellis, P.R. (1979) Complementary contributions from insecticides and host-plant resistance for control of carrot rust fly (*Psila rosae* F.) on main-crop carrots. *Abstracts of papers: IX International Congress of Plant Protection and 71st Annual Meeting of the American Phytopathological Society* No. 439.

Thompson, A.R.; Harris, C.R. (1982) An indication of phorate-tolerance in a population of carrot fly from East Anglia. *Tests of Agrochemicals and Cultivars (Annals of Applied Biology 100* Supplement), No. 3, pp. 18-19.

Thompson, A.R.; Percivall, A.L. (1978) Compatibility of insecticides on transplanted Brussels sprouts. Report of the National Vegetable Research Station for 1977, pp.73-74.

Thompson, A.R.; Suett, D.L. (1982) Developments in insecticidal control of insect pests of U.K. vegetables. Scientific Horticulture 33, 90-99.

Thompson, A.R.; Kempton, D.P.H.; Percivall, A.L. (1984) The use and precision of insecticide granule applications for protecting brassicas against cabbage root fly. Proceedings British Crop Protection Conference - Pests and Diseases 3, 1123-1128.

Thompson, A.R.; Percivall, A.L.; Edmonds, G.H. (1982a) Effects of type of seed drill on control of cabbage root fly and carrot fly. Report of the National Vegetable Research Station for 1981, p. 31.

Thompson, A.R.; Percivall, A.L.; Edmonds, G.H. (1983) Carrot fly: control by seed coating. Report of the National Vegetable Research Station for 1982, p. 26.

Thompson, A.R.; Percivall, A.L.; Suett, D.L.; Edmonds, G.H. (1986) Effects of depth of placement of granules at drilling on the performance of insecticides against cabbage root fly (Delia radicum) and carrot fly (Psila rosae) on root vegetables. Aspects of Applied Biology 12.

Thompson, A.R.; Suett, D.L.; Percivall, A.L. (1982b) The protection of carrots against carrot fly (Psila rosae) with granular and emulsifiable concentrate formulations of chlorfenvinphos incorporated in gels used for drilling pre-germinated seed in a sandy loam. Annals of Applied Biology 101, 229-237.

Tolman, J.H.; McLeod, D.G.R.; Harris, C.R. (1986) Yield losses in potatoes, onions and rutabagas in southwestern Ontario, Canada - the case for pest control. Crop Protection 5, 227-237.

Wall, C.; Garthwaite, D.G.; Blood Smyth, J.A.; Sherwood, A. (1986a) Efficacy of sex-attractant monitoring for the pea moth, Cydia nigricana (F.), in England. Annals of Applied Biology 110.

Wall, C.; Garthwaite, D.G.; Greenway, A.R.; Biddle, A.J. (1986b) Prospects for pheromone monitoring of the pea moth, Cydia nigricana (F.), in vining peas. Aspects of Applied Biology 12.

Way, M.J.; Cammell, M.E.;vTaylor, L.R.; Woiwod, I.P. (1981) The use of egg counts and suction trap samples to forecast the infestation of spring-sown field beans, Vicia fabae, by the black bean aphid, Aphis fabae. Annals of Applied Biology 98, 21-34.

Wheatley, G.A. (1986) Supervised and integrated control: foliage pests of Brussels sprouts. Report of the National Vegetable Research Station for 1985, pp. 34-35.

Wheatley, G.A.; Thompson, A.R. (1981) Pest damage and insecticide performance in vegetable crops for processing. In: Quality in Stored and Processed Vegetables and Fruit (Eds P.W. Goodenough and R.K. Atkin). Academic, London, pp. 165-175.

Whitehead, A.G.; Tite, D.J.; Bromilow, R.H. (1981) Techniques for distributing non-fumigant nematicides in soil to control potato cyst-nematodes, Globodera rostochiensis and G. pallida. Annals of Applied Biology 97, 311-321.

A BENZOYLPHENYL UREA FOR RATIONAL CONTROL OF PESTS ON FRUIT AND VEGETABLES

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ABSTRACT

Various field tests have been made in different countries against insect pest using XRD-473, a new benzoylphenyl urea insecticide which has low mammalian toxicity, no known environmental problem and no observed negative effect on parasites or predators. Performance was excellent against major pests including resistant populations of Spodoptera littoralis and Psylla pyri ; it was better than diflubenzuron in most trials and equal to chlorfluazuron agianst S. littoralis. It was also generally equal to or better than standard insecticides of other chemical classes. Although XRD-473 kills primarily via ingestion by larvae, it has considerable contact, as well as ovicidal, activity. For maximum efficacy, applications should be made when adults are present, at or before egg-laying, to take advantage of ovicidal and larvidical activity. Timing of applications should be based on egg counts and on peaks of adult activity, as well as on larvae counts.

INTRODUCTION

Scientists have expressed their views that benzoylphenyl urea (BPU) analogues possess good insecticide activity against pests of forestry, row crops, humans and livestock, and may become an important part of pest management control strategies (Wright and Retnakaran, 1984). BPUs are usually of low toxicity to parasites and predators and do not lead to an increase of mites in some crops investigated (Purcell and Granett, 1985; Riedl and Hoying, 1980; Sbragia et al., 1983). Additionnal effects that cannot be measured in small field trials have been attributed to BPUs. Pupae and adults may die if, earlier in their life cycle, they have been treated with XRD-473 or chlorfluazuron (Radwan et al., 1985). Diflubenzuron reduced boll weevil (Anthonomus grandis grandis) reproduction more than 90 % by affecting mainly its eggs and the newly hatched larvae (Ganyard et al., 1978), and completely suppressed reproduction of large milkweed bug (Oncopeltus fasciatus) by inducing sterility in males through impairing their ability to transfer sperm (Redfern et al., 1980). For the above reasons, wide use of the most effective BPUs may be expected for rational control of pests on fruit, vegetables and other crops.

Commercial success of BPUs has been limited mainly to uses against resistant strains of the cotton leafworm (Spodoptera littoralis) in cotton in Egypt where they are mixed with other insecticides to control the entire pest complex (Komblas and Rizk, 1973); against Plutella spp. in crucifers in the Pacific; and in forestry. Lack of greater commercial success is attributed to 1) the misconception that BPUs are only slow stomach poison insecticides, while their ovicidal and early larvicidal activity has not been taken into consideration; 2) poor timing of application; 3) high cost; 4) weaker activity of the first discovered BPU. XRD-473 has greater larvicidal and contact activity than other BPUs (Sbragia et al., 1983). A number of field tests have been made in different countries to define the efficacy of XRD-473 against some major insect pests as well as its viability as a commercial product. A summary of the results on fruit and vegetable pests is presented here.

MATERIALS AND METHODS

All trials were made using high volume sprays and crops were sprayed to run-off. In France and Turkey, Solo atomiser sprayers were used; in Italy and Greece, high power lance applicators; and in Egypt, knapsack sprayers. An effort was made in most trials to spray early in the egg stage defined by the peak of adult trapping by local plant protection services or by visual observation of number of eggs. In all trials, 4 replicates were used, unless otherwise indicated. In orchards, 1 to 3 trees were used per plot depending on the size. In other crops, size of plots used are indicated. XRD-473 is an experimental insect growth regulator insecticide of the Dow Chemical Company, belonging to the BPUs, with chemical name: N-(((3,5-dichloro, 4-(1,1,2,2-tetrafluoroethoxy) phenyl) amino)-carbonyl)-2,6,-difluorobenzamide. In all trials a 5 % wt/vol EC formulation was used. Where data are reported in percentages, the Abbott formula was used.

RESULTS

Apples

Codling moth, Laspeyresia pomonella, France, 1985

Branches of treated apple trees were enclosed in muslin cloth cages and were infested with 20 moths (10 couples) each, 1 day after the first spray. Each cage contained 4 apples. Evaluation of apple injuries was made 5 days after the 2nd spray by cutting open the apples. There was no natural infestation of the apples outside the cages. Results in Table 1 show that XRD-473 at rates as low as 50 g.a.i./ha gave good control of codling moth.

TABLE 1
Control of L. pomonella on apples

Treatment	g a.i./ha*	Injuries per 16 apples		
		Shallow Entry	Deep Entry	Total
XRD-473	50	1	3	4
	100	1	3	4
Phosalone	600	2	4	6
Diflubenzuron	100	3	11	14
Untreated	-	12	11	23

* Volume 800 l/ha, sprays 25 June, 5 July.

Leafminers, Lithocolletis blancardella, Leucoptera scitella France, Italy, 1985

In a trial in France, 3 sprays were made for the control of L. blancardella; in a trial in Italy, one spray was made for control of L. blancardella and L. scitella. Efficacy was evaluated by examining 100 leaves and recording the number of mines.

Results in Table 2 show that XRD-473 at rates as low as 12.5 g a.i./ha and diflubenzuron at 100 g a.i. per ha (the only rate tested) gave excellent control at both locations, while phosalone gave very poor control in France, where it was included as a standard.

TABLE 2
Control of leafminers on apples

Treatment	g a.i./ha	Mines per 100 leaves			
		France		Italy	
		15 DAT*2	10 DAT*3	34 DAT*	34 DAT**
XRD-473	12.5	4	2	1	2
	25	3	2	0	2
	50	2	2	0	1
Phosalone	600	26	67	-	-
Diflubenzuron	100	4	3	0	4
Untreated	-	41	66	11	16

* L. blancardella ** L. scitella
Spray volume, France - 800-950 l/ha; Italy - to run-off

Pears

Pear psylla, Psylla pyri France, Italy, Greece 1985-1986

In tests at 3 locations, five infested shoots were marked in each of 4 replicates before trees were treated. Results in Table 3 indicate that in France, XRD-473 at 100 g a.i./ha gave very good control, equal to that of amitraz standard. It was slightly better in the first spray (T1) than diflubenzuron at the same rate.

TABLE 3
Control of P. pyri on pears, France, 1985

Treatment	g a.i./ha	Nymphs per terminal	
		7 DAT1	7 DAT2
XRD- 473	50	30	2
	100	7	1
Amitraz	600	7	2
Diflubenzuron	100	14	1
Untreated	-	128	19

Spray volume - 400 l/ha, 2 sprays, 4 and 24 June.

In tests in Italy and Greece (Table 4) the rate of 10 g a.i./100 l of XRD-473 gave the best results. In Italy, it was better than standard amitraz at 60 g a.i./100 l and diflubenzuron at 10 g a.i./100 l plus oil at 0.3 l/100 l; in Greece, it was equal to amitraz and slightly better than diflubenzuron or diflubenzuron mixed with oil at 0.5 l/100 l.

TABLE 4
Control of Pear psylla, Italy - Greece, 1986

Treatment	g a.i./100 l	Nymphs per terminal			
		Italy		Greece	
		10 DAT	18 DAT	14 DAT	28 DAT
XRD-473	5	9	16	8	6
	10	7	12	5	4
Diflubenzuron	10	-	-	10	5
Diflubenzuron/oil	10/0.3-0.5 l	18	16	10	4
Amitraz	60	18*	13**	4	4
Untreated	-	45	50	34	23

* 5 DAT, ** 13 DAT (Amitraz was applied 5 days later)

Grapes

Grape berry moth, *Lobesia botrana*, France 1985

One application against the 2nd generation was made at the black-head egg stage and one against the 3rd generation, when part of the eggs had hatched. Each treatment included 4 replicates, each having 10 grape vines. Assessments were carried out 10 days after each spray by picking up and examining 50 fruit clusters per plot, and counting the number of live larvae per cluster. The results in Table 5 show that both rates of 50 and 100 g a.i./ha gave good control, similar to chlorpyrifos at 300 g a.i./ha.

TABLE 5

Control of *L. botrana* on grapes

Treatment	g a.i./ha	Larvae per 100 fruit clusters	
		2nd generation	3rd generation
XRD-473	50	11	24
	100	9	8
Chlorpyrifos	300	3	23
Untreated	3	191	392

Sprays 2 July, 18 August. Spray volume 300 l/ha

Olives

Olive fruit moth, *Prays oleae*, Greece 1986

One application against the flower generation was made at the peak of adult flight. XRD-473 gave good results at rates 2.5 to 10 g a.i./ 100 l, better than diflubenzuron at equivalent rates (Table 6). The failure of *Bacillus thuringiensis* may be attributed to early spraying.

TABLE 6

Control of *P. oleae* on flower clusters

Treatment	g a.i./100 l	Larvae per 100 clusters 20 DAT	% infested clusters 30 DAT
XRD-473	2.5	6	23
	10	3	6
Diflubenzuron	2.5	15	29
	10	9	15
B. thuringiensis	50	21	38
Untreated	-	27	43

Potatoes

Colorado potato beetle, *Leptinotarsa decemlineata*, Italy 1986

Trials were made in two locations at a time when the majority of the population was in the larva stage (Volghera, 95.3%; Spazzate, 97.6%). In both places the plot size was 5 x 5 m. with 4 replicates; applications of azinphos-methyl and cypermethrin were made one week after the application of XRD-473 since they are mainly contact insecticides. Table 7 indicates that low rates of XRD-473, 12.5 to 25 g a.i./ ha, gave good results. The initial activity of XRD-473 was slightly inferior to the other products, while its residual action was better than azinphos methyl and about equal to or better than cypermethrin.

TABLE 7

Number of live larvae of *L. decemlineata* on 14.4 m row (10m2) of potato plants, Italy, 1986

Treatment	g a.i./ha	Volghera (Pv)		Spazzate (Ra)	
		5 DAT	21 DAT	7 DAT	23 DAT
XRD-473	12.5	191	15	9	2
	25	83	6	6	1
	50	122	0	15	0
		3 DAT	15 DAT	3 DAT	16 DAT
Azinphos-methyl	350	12	59	-	-
Cypermethrin	50	13	0	1	2
Untreated	-	473	89	99	64

Vegetables

Various vegetable crops, including tomatoes, peppers, cabbages, beets, etc. in additon to cotton, are infested by the cotton leafworm (*S. littoralis*) and by the American bollworm (*Heliothis armigera*). Trials have been made for both pests in cotton. Results of these trials are presented here to indicate utility of XRD-473 for control of these pests on vegetables.

S. littoralis, Egypt, 1984-1986

Trials were made in the field using artificial infestation with egg-masses or with clusters of young larvae on detached leaves collected from the field and placed on cotton plants which were growing under 2 x 2 x 2 m. screen cages. Each cage covered 3 cotton rows, each 2 m. long. Eggmasses were attached with paper clips to the underside of the leaves.

In the first trial 30 clusters of 1st-2nd instar larvae were used per treatment (cage). Each cluster came from one eggmass and was on one leaf. Ten such leaves with clusters of larvae were attached to cotton plants in each row, 3 days after the application of the chemicals as described in the foregoing paragraph. Table 8 indicates that XRD-473 at 24 g a.i./ha gave results better than diflubenzuron used at 48 or 72 g a.i./ha. The commercial standard Empire* insecticide also gave excellent results.

TABLE 8
Control of *S. littoralis* larvae placed on cotton plants 3 days after application

Treatment	g a.i./ha	No live larvae 2 m cotton		% Foliage Damage**
		5 DAT	8 DAT	
XRD-473	24	16	0	0.3
	48	2	0	0.2
	72	4	0	0.1
Diflubenzuron	48	94	19	9.8
	72	62	3	5.0
Chlorpyrifos/ Diflubenzuron	1152/72	0	0	0
Untreated	-	90	45	78.2

**15 DAT

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* Trademark of the Dow Chemical Company. Flowable concentrate formulation contains : chlorpyrifos/diflubenzuron 480/30 g a.i./l.

In another trial, 40 eggmasses per treatment were placed on leaves *before* spraying. Results in Table 9 show that at the rates tested XRD-473 was superior to chlorfluazuron in preventing hatching of egg-masses. One eggmass was considered as hatched when even one egg had hatched. Both materials gave very good control when the number of larvae were counted 8 DAT.

TABLE 9
Number of hatched eggmasses and live larvae after treating cotton plants bearing eggmasses

Treatment	g a.i./ha	Hatched eggmasses	Live larvae/cage 8 DAT
XRD-473	48	11	45
	72	9	41
Chlorfluazuron	48	22	61
	72	17	41
Untreated	-	36	409

In a third trial, 200 larvae of 2nd-3rd instar were placed in each cage 5 and 10 days after spray to check the residual activity of the products. Larvae were in small clusters on detached leaves and were attached to the cotton plant leaves with paper clips. Evaluation was made 8 days later, or 13 DAT and 18 DAT. Results in Table 10 show that both XRD-473 and chlorfluazuron gave good residual control of larvae.

TABLE 10
Control of S. littoralis larvae placed on treated cotton plant

Treatment	g a.i./ha	% control larvae	
		13 DAT*	18 DAT**
XRD-473	48	79	43
	72	89	56
	144	97	81
Chlorfluazuron	48	86	45
	72	94	72
Untreated	-	(71)***	(73)***

* Infestation made 5 days after treatment
** Infestation made 10 days after treatment
*** Number live.

H. armigera, Turkey 1984-1985

In an area where *H. armigera* has developed resistance to pyrethroids cotton plants were treated when population per 27 meter (3 plots x 9 meters) sections of row, was:

1984: eggs, 72; larvae, 23. 1985: Eggs, 130; larvae, 102. Plot size was 100 m2 and 3 replicates were included in each treatment both years. Counts were made on three 3-meter sections of row in each plot before spray and 4, 7 and 10 DAT. Results in table 11 show that neither XRD-473 nor cypermethrin gave a high level of control. However, the mixture of XRD-473 and cypermethrin gave a considerably higher level of control.

TABLE 11
Control of H. armigera on cotton

Treatment	g a.i./ha	Average % control 1984	Average % control 1985
XRD-473	50	72	63
	100	65	74
Cypermethrin	100	76	77
XRD-473/cypermethrin	50/100	85	75
	100/100	92	86
Untreated	-	(63)*	(64)*

* Average number live larvae per 27 m. cotton row

DISCUSSION AND CONCLUSION

In a series of field tests, XRD-473 was found to be very effective for a number of pests of horticultural crops. In general, it was as effective as amitraz, organophosphate and commercial standards, but at much lower rates. At equal rates in the majority of pests, it was better than diflubenzuron and equal to chlorfluazuron against S. littoralis.

XRD-473 exhibits ovicidal action and best results are obtained when applications are timed to take advantage of both ovicidal and larvicidal activity. When applications are made at the peak of adult flight, adults may lay unfertile eggs, or eggs may be killed by direct spray or spray de-deposits on leaf or fruit surface where eggs are laid; surviving larvae will be killed after hatching due to long residual action. XRD-473 is effective on some pests that are highly resistant to standard contact insecticides, e.g.: S. littoralis and P.pyri.

XRD-473 promises to be an excellent insecticide for use on horticultural crops, particularly where pest management programs are used, due to its 1) efficacy on pests resistant to other types of insecticides 2) broad spectrum of activity against leaf and fruit feeding larvae; 3) ovidical activity; 4) long residual activity; 5) little detrimental effect on parasites and predators; 6) low mammalian toxicity; and 7) favorable environ-mental characteristics. Because the mode of action of BPUs is unique XRD-473 should be useful in mixtures or in alternation with insecticides of other chemical classes to prevent development of resistance.

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REFERENCES

Ganyard, M.C.;Bradley, J.R.Jr.; Brazzel, J.R. (1978) Wide-area field test of diflubenzuron for control of an indigenous boll weevil population Journal of Economic Entomology 62, 244-245.

Komblas, K.N.; Rizk, G.A.(1973). Laboratory trials with field residues of PH-6038 (DC-201) and PH-6040 (DC-202) against the Egyptian cotton leafworm (Spodoptera littoralis). Dow Chemical Europe S.A. R and D Report. GHE-P-047 pp 12.

Purcel, M.; Granett, J.(1985) Toxicity on benzoylphenyl ureas and thuringiensin to Trixoys pallidus (Hymenoptera: Braconidae) and walnut aphid (Homoptera: Aphididae). Journal of Economic Entomology 78, 1133-1137.

Radwan, H.S.A.; Amar, I.M.A.; Eisa, A.A.K; El-Sheikh, A.E.A.; El-Bermawi, Z.A.; Farag, A.I. (1985) Initial and latent bioactivity of five insect growth regulators on development and reproduction of the cotton leafworm Spodoptera littoralis(Boisd.). Proceedings 6th Arab Pesticides Conference, Tanta University,p.30

Redfern, R.E.; Demilo, A.B.; Borcovec, A.B.(1980) Large milkweed bug: effects of diflubenzuron and its analogues on reproduction. Journal of Economic Entomology 64, 682-684

Riedl, H; Hoying, S.A.(1980) Impact of fenvalerate and diflubenzuron on target and not target arthropod species on Bartlett pears in northern California. Journal of Economic Entomology 73,,117-122

Sbragia, R.J. ; Bisabri-Ershadi, B.; Risterink, R.H.; Clifford, D.P.; Dutton R.(1983) XRD-473, a new acylurea insecticide effective against Heliothis. Proceedings 10th International Congress of Plant Protection 1983 1, 417-424.

Wright, J.E.; Rednakaran A.(1984) Control of insects with benzoylphenyl ureas. Abstracts 17th International Congress of Entomology. p 149

MANAGEMENT OF STRAWBERRY GREY MOULD WITH FUNGICIDES TARGETED AGAINST INOCULUM IN CROP RESIDUES

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ABSTRACT

Dead strawberry leaves are the main source of initial inoculum of ***Botrytis cinerea*** in epidemics of grey mould fruit rot in Ontario. Dead leaves present at the blossoming and fruiting stages (the time of infection) were produced in the preceding autumn or in early spring. Potential sporulation by ***B. cinerea*** during the blossoming-fruiting period was high on leaves colonised by the pathogen and placed in the field during October to April. Myclozolin applied in the autumn reduced sporulation incidence on the dead leaves but not on the fruits in the spring. Pre-blossoming applications of propionic acid, chlorothalonil or myclozolin to the green and dead leaves in the spring reduced potential sporulation on the dead leaves at blossoming and the incidence of grey mould fruit rot. However, only myclozolin was as effective as conventional captan sprays applied during blossoming and fruiting. Residues from fungicides applied before blossoming were low or undetectable, but where captan was applied to the foliage at blossoming residues were substantial.

INTRODUCTION

Grey mould fruit rot of strawberry, caused by ***Botrytis cinerea***, is usually managed by fungicide sprays applied when the crop is at the flowering and fruiting stages. Unfortunately, this practice may result in fungicide residues on the fruits and the development of ***B. cinerea*** populations which are resistant to certain fungicides, especially those with single-site activity (Dekker 1976). An alternative management strategy proposed by Powell (1952) and Jarvis (1962a) is to suppress the production of initial inoculum by the pathogen. Powell (1952), Jordan and Pappas (1977) and Jenkins (1968) applied this strategy with partial success. Development of a practice for suppressing production of initial inoculum requires identification of the inoculum sources, an effective agent for suppressing or eradicating the pathogen, and epidemiological information for rational use of the agent.

In Ontario, mycelia of ***B. cinerea*** in dead host leaves are the principal source of initial inoculum in grey mould epidemics (Braun & Sutton 1985). This contrasted with the observations in Scotland that major inoculum sources included sclerotia and mycelia of the pathogen on host residues, weeds and straw (Jarvis 1962b). Both Jarvis (1962b) and Jordan and Pappas (1977) noted that the initial inoculum arises mainly within the strawberry field.

Fungicides with known effectiveness against mycelia of ***B. cinerea*** in dead host leaves include chlorothalonil, myclozolin, and propionic acid (Braun & Sutton 1984). The purposes of the present study were to establish a rationale for timing applications of these fungicides to dead strawberry leaves, and to examine the effectiveness of this strategy in managing grey mould fruit rot.

MATERIALS AND METHODS

Substrate production

The production, maturation and death of strawberry leaves in field plots of cv Redcoat were quantified between 8 July and 19 November 1985, and 7 April and 14 July 1986. These study periods spanned the interval from crop renovation in 1985 to that in 1986 except for the period of freezing and snow cover (November to March). Two 0.5 m^2 areas of matted row, each comprising about 50 strawberry crowns, were used for the study. At weekly intervals, plastic nursery tags were attached to the petioles of each leaf which had become fully expanded during the preceding 7 days. At the same time, all leaves which had died (turned brown) were removed. The population dynamics of the leaf substrate were then determined with respect to time.

Potential sporulation

Potential sporulation of *B. cinerea* on strawberry leaves colonised by the pathogen and exposed in strawberry field plots was quantified in relation to season and time of exposure. Leaf discs (8 mm diameter) were punched from healthy strawberry leaves, autoclaved, allowed to cool, then dipped in a conidial suspension of *B. cinerea* (10^6 spores/ml) to which a drop of surfactant (Triton X-100) had been added. The discs were positioned adaxial side upwards in Petri dishes, which were sealed with 'Parafilm' and kept at 18°C for about 72 h. The discs were then air dried at 18°C and ten of them placed in each of a series of mesh bags (10 cm x 10 cm), made of black nylon flyscreen. Bags with freshly-colonised discs were positioned at random in the leaf litter of three plot areas in a strawberry field (cv Redcoat) on 31 August 1984. One bag was taken from each plot at monthly intervals thereafter until May 1985. At each time of sampling, bags of freshly-colonised discs were placed in the plots. These bags were collected on 14 June 1985 to coincide with blossoming and early fruit formation of the strawberries. Retrieved discs were incubated on moist filter paper in Petri dishes for 5 days at 20°C to favour sporulation. Incidences of sporulation of *B. cinerea* on the leaf discs were recorded.

Inoculum suppression trials

Fungicides for suppressing the production of inoculum in spring were sprayed on plots of strawberry cv Veestar or Redcoat in the autumn or before the time of blossoming in the spring. Each plot consisted of three matted rows each 4 m long. Myclozolin 50 WP (0.5 kg product/ha), chlorothalonil 50 F (3.5 l product/ha), and propionic acid, reagent grade (23.8 l/ha) were applied to the plants and dead leaves on 29 September, and 13 and 27 October 1984, or on 4 and 18 April and 2 May 1985. As a conventional treatment, captan 80 WP (6.75 kg product/ha) was applied to protect the flowers and fruits on 18 and 29 May and 4 June 1985. The fungicides were applied in 476 l water/ha at 207 kPa using an air-pressurised backpack sprayer with four 8002E 'TeeJet' nozzles mounted on a boom. The centre pair of nozzles directed spray downwards and the outer nozzles were mounted on drop pipes to direct spray laterally into the crop canopy. A horizontal bar mounted ahead of the nozzles parted the canopy to facilitate spray deposition on the leaf residues. The bar was removed for captan applications. Potential sporulation of *B. cinerea* was estimated on the dead leaves and the fruits. Twenty dead leaves were collected from each plot on 7 June 1985 and incubated on galvanised wire mesh in a humid atmosphere within plastic boxes for 5 days at 20°C. One to two hundred ripe berries were picked in each plot on 13 and 21 June 1985 and incubated under the same conditions as the leaves. Sporulation on the incubated leaves and fruits was recorded.

Fungicide residues

Ripe strawberries picked at random from each of the treatments on June 28, 1985 were analysed for fungicide residues by the Ontario Pesticide Residue Laboratory.

RESULTS

Strawberry leaf populations

Production of strawberry leaves after the plants were defoliated during renovation (8 July 1985) peaked in late July, early September, and early May (Fig. 1). Death of leaves produced in July was first observed near the beginning of September, and during October the death rate was similar to the production rate. The life duration of leaves which died in the autumn averaged about 11 weeks. Peaks of leaf death were observed after straw removal in April, in the last week of May and between 16 and 24 June. All leaves emerging after 21 September survived the winter, appeared green and healthy in April and early May, and most died in late May. Most leaves which emerged between 14 April and 5 May died during the death peak of 16 to 24 June.

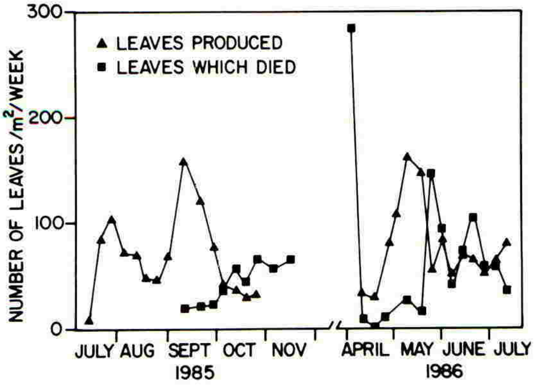

Fig. 1. Numbers of strawberry leaves produced or which died during successive weeks between 8 July 1985 and 14 July 1986.

Potential sporulation

Sporulation by *B. cinerea* on leaf discs placed in the field on 31 August declined markedly during October, showed little change during the period of freezing and snow cover (November to March), but declined again before the end of May (Fig. 2). Sporulation in June on leaf discs placed in the field in September was only 20%. However the pathogen sporulated on all discs placed in the field between October and April and exposed in the humidity chambers in June.

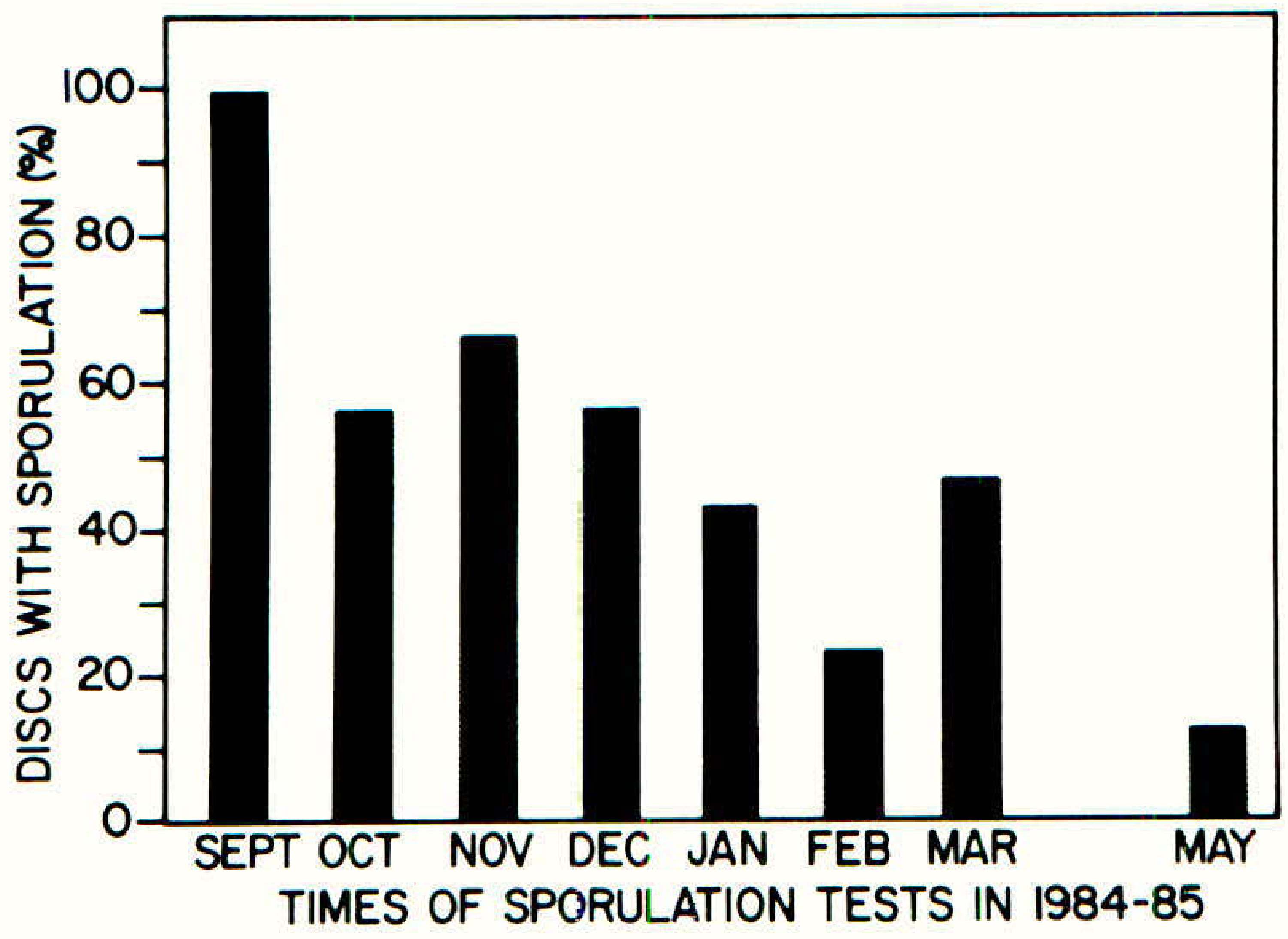

Fig. 2. Sporulation of *B. cinerea* on colonised leaf discs which were placed on strawberry leaf litter in field plots on 31 August 1984, retrieved at monthly intervals, and incubated to promote sporulation.

Suppression of inoculum trials

Of the fungicides applied in the autumn, only myclozolin suppressed sporulation by *B. cinerea* on the leaves during the following June. None of the fungicides, including the standard captan treatment, reduced grey mould fruit rot (Table 1). However the incidence of fruit rot was low in the untreated and in fungicide-treated plots.

TABLE 1

Effects of fungicides applied in the autumn on potential sporulation of *B. cinerea* on the dead leaves and fruits in the following June.

	Incidence of sporulation (%)	
Fungicide	Leaves	Fruit
Untreated	14 b[+]	8
Captan (standard)[++]	11 b	6
Propionic acid	20 b	10
Myclozolin	7 a	10
Chlorothalonil	16 b	10

[+] Applied during blossoming and fruiting in spring.

[++] Means in a column followed by the same letter are not significantly different at p=0.14 (Friedman's multiple range test on ranked means).

Myclozolin and chlorothalonil applied before blossoming in the spring suppressed sporulation on the leaves in June, and were as effective as captan applied at intervals during blossoming and fruiting (Table 2). Propionic acid failed to suppress sporulation on the leaves.

All fungicides applied in spring reduced sporulation by *B. cinerea* on the fruits (Table 2). Myclozolin applied before blossoming was as effective as the conventional captan treatment. Propionic acid and chlorothalonil were less effective than captan.

TABLE 2

Effects of fungicides, applied prior to blossoming in the spring, on potential sporulation of *B. cinerea* on the dead leaves and fruits in the following June.

	Incidence of sporulation (%)	
Fungicide	Leaves	Fruit
Untreated	19 b+	34 c
Captan (standard)++	7 a	12 a
Propionic acid	19 b	19 b
Myclozolin	1 a	13 a
Chlorothalonil	5 a	21 b

\+ Applied during blossoming and fruiting in spring.
++ Means in a column followed by the same letter are not significantly different p=0.29 (Friedman's multiple range test on ranked means).

Fungicide residues

Residues of captan and chlorothalonil, but not of myclozolin, were detected in the fruits. The residue concentrations were 3.4-3.7 mg captan /kg fruit, and 0.006 to 0.019 mg chlorothalonil/kg fruit.

DISCUSSION

Dead strawberry leaves present during the period of blossoming and fruiting have been recognised as the main source of initial inoculum of *B. cinerea* in epidemics of grey mould fruit rot in Ontario (Braun & Sutton 1985). The present study showed that a large proportion of these leaves are produced in the autumn and die during the early part of the blossoming and fruiting period (late May). In addition, leaves produced in spring before 5 May die late in the blossoming period and may become an inoculum source at that time.

Potential sporulation by *B. cinerea* in the blossoming-fruiting period was high on the colonised leaf discs placed in the field during October to

April but low in discs first exposed in August or September. Accordingly, strawberry leaves produced and infected by the pathogen in the autumn or in early spring, and which died before or during the blossoming-fruiting period, were the principal inoculum source of *B. cinerea*. These leaves are the target of fungicide treatments applied for suppressing initial inoculum in the control of grey mould fruit rot.

The activity of myclozolin applied in the autumn in suppressing sporulation incidence on the leaves in the following June may have resulted both from eradicant activity against *B. cinerea* in the dead leaves and from protectant activity on the green leaves. Suppression of the pathogen in the dead leaves may have reduced inoculum incidence and thus infection frequency of green and senescing leaves in the autumn. Reduced infection frequency by this mechanism or by protection would probably result in lower incidence of sporulation on the infected leaves after they died in the spring.

Myclozolin applied before blossoming in the spring managed grey mould fruit rot as effectively as the conventional captan sprays applied at the time of blossoming and fruiting. Propionic acid and chlorothalonil also suppressed fruit rot when applied before blossoming but were less effective than myclozolin or captan. An important feature of the pre-blossoming treatments was that little or no fungicide residue was detected in the harvested fruits in contrast to the substantial amounts of captan which were found in the conventional treatment. The key epidemiological effect of the pre-blossom sprays appeared to be suppression of inoculum production by *B. cinerea* on the dead leaves during the period when the blossoms were receptive to the pathogen. We conclude that grey mould fruit rot may be managed successfully using fungicides targeted against the sources of initial inoculum of *B. cinerea* and applied before blossoming begins in spring.

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REFERENCES

Braun, P.G.; Sutton, J.C. (1984) Effectiveness of fungicides in reducing inoculum production by *Botrytis cinerea* in dead strawberry leaves. Proceedings British Crop Protection Conference - Pest and Diseases 3, 971-974.

Braun, P.G.; Sutton J.C. (1985) Management of strawberry gray mold with fungicides applied to host residues. (Abstr.) Canadian Journal of Plant Pathology 7, (4) 442-443.

Dekker, C. (1976) Acquired resistance to fungicides. Annual Review of Phytopathology 14, 405-428.

Jarvis, W.R. (1962a) The epidemiology of *Botrytis cinerea* Pers. in strawberries. Proceedings 16th International Horticultural Congress 258-262.

Jarvis, W.R. (1962b) The infection of strawberry and raspberry fruits by *Botrytis cinerea* Fr. Annals of Applied Biology 50, 569-575.

Jenkins, P.T. (1968) The effects of soil management and fungicides on the development of grey mould (*Botrytis cinerea*) on strawberries. Australian Journal of Experimental Agriculture and Animal Husbandry 8, 374-376.

Jordan, V.W.L.; Pappas A.C. (1977) Inoculum suppression and control of strawberry Botrytis. Proceedings British Crop Protection Conference - Pests and Diseases 341-348.

Powell, D. (1952) The effect of early spring fungicides on *Botrytis cinerea*. Plant Disease Reporter 36, 97-98.

INTEGRATED CHEMICAL APPLICATIONS FOR THE CONTROL OF CLUBROOT OF BRASSICAS

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ABSTRACT

In a glasshouse evaluation of twenty-six single and combination treatments of fungicides, herbicides and trace elements, using Chinese cabbage grown in soil artificially infested with resting spores of Plasmodiophora brassicae, the best overall control of clubroot incidence and severity was obtained when thiophanate-methyl at 250 mg/kg with sulphur at 15 mg/kg was incorporated into the soil. This treatment also gave the highest fresh shoot weight with yields almost equal to the uninoculated control. Tolclofos-methyl at 250 mg/kg either alone or in the combinations tested was less effective than thiophanate-methyl. The herbicides trifluralin at 10 mg/kg and napropamid at 10 mg/kg used alone did not affect the disease but in combination with either boron at 250 mg/kg or sulphur at 15 mg/kg, trifluralin reduced disease incidence though not severity. In single treatments neither boron nor sulphur affected the disease and in combination treatments their relative effects were similar. Some phytotoxicity symptoms were observed when boron was used.

INTRODUCTION

Clubroot disease of Cruciferae, caused by Plasmodiophora brassicae Wor., remains one of the most serious diseases associated with intensive brassica cultivation. Various chemicals have been tested for control of P. brassicae and while many affect clubroot disease to some extent, none, with the possible exception of calomel, is consistently satisfactory. However, the use of this persistent fungicide has become increasingly unacceptable. The only remaining acceptable standard treatment is thiophanate-methyl, but the efficacy of benzimidazole fungicides is variable, incomplete and dependent on climate and level of soil infestation (Il'ina 1979).

In addition to the fungicides screened, herbicides, trace elements, fertilisers and insecticides have been assessed. The herbicides trifluralin and napropamid have been shown to reduce the incidence of clubroot disease (Buczacki 1973, Robak & Dobrzanski 1978). The trace element sulphur, either alone or in combination with the fungicide zineb has been reported to decrease disease incidence (Asyakin 1981, Vladimirskaya et al. 1981) and to increase yield (Vytskii 1979, Dunin et al. 1981). Disease incidence has also been reduced and yields increased by the application of boron (Antonova et al. 1975, Anon 1985).

These agrochemicals have generally been evaluated alone but in some instances they have been combined. Robak & Dobrzanski (1978) used trifluralin or napropamid with carbendazim and reported more efficient disease control compared with carbendazim alone. A colloidal sulphur and zineb mixture has been recommended for the control of clubroot in Russia (Polyakov et al. 1975). In this study the effects of fungicides, herbicides and trace elements either alone or in combination were examined with the objective of assessing the practical possibility of increased control using combinations of materials normally applied in brassica production.

MATERIALS AND METHODS

In this randomised block glasshouse pot experiment twenty six treatments were evaluated by incorporation into soil which was subsequently infested with resting spores of *P. brassicae*. Controls consisted of one inoculated and one uninoculated treatment. The chemicals listed in Table 1 either alone or in selected combination treatments (Table 2) were incorporated at fixed rates.

TABLE 1

Identity and rates of incorporation of chemicals

Agrochemical type	Active ingredient	Rate mg a.i./kg	Product	Formulation
Fungicide				
	Thiophanate-methyl	250	Cercobin (May and Baker)	50% dust
	Tolclofos-methyl	250	Rizolex (F.B.C.)	10% dust
Herbicide				
	Trifluralin	10	Treflan (Elanco)	48% w/v e.c.
	Napropamid	10	Devrinol (Stauffer)	45% w/v e.c.
Trace element				
	Boron	250	Borax (Hopkin & Williams)	100% dust
	Sulphur	15	Micronised sulphur (Hoechst)	80% w.p.

The rates chosen for the herbicides and trace elements were those which had previously given reported reduction of clubroot without phytotoxicity. 1.0 kg of an air-dried brown earth soil of pH 5.7 was used for each of the five replicate 13 cm pots and both chemicals and inoculum were accurately dispensed for each pot. When a combination of chemicals was used each material was separately and thoroughly mixed with the soil and in all cases inoculation followed chemical treatments immediately.

The inoculum was prepared by homogenising in distilled water, for 2 min, a mixture of fresh and frozen clubbed roots of diseased cabbage (*Brassica oleracea* cv. Celtic) collected from a single crop. The homogenate was filtered through four layers of muslin and the filtrate then centrifuged at 2,000 rev/min (RCF 653) for 7 min. The pellet containing resting spores was washed twice by repeated centrifugation and a stock spore suspension prepared such that 20 ml when mixed into the prepared soil gave an inoculum level of 10^7 spores/g. Treated and inoculated soils were transferred to pots and a layer of peat compost (1-2 cm deep) was added on the surface to reduce the likelihood of damping off (Johnston 1968).

Twenty five 6-day-old seedlings of Chinese cabbage (*Brassica campestris* var. *pekinensis* cv. Chiko), propagated in a sterile compost were transplanted into each pot. After 2 weeks, seedlings were thinned to a stand of 15 plants per pot and grown on and harvested after 7 weeks. Air temperature from time of sowing to lifting of plants was maintained at a minimum of 20°C and ventilation was provided at 24°C. Soils were maintained at container capacity by daily watering. Additional lighting, from high pressure 400 W mercury vapour lamps, was employed to maintain a 16 h day-length throughout the experiment. At harvesting the plants were carefully removed from the pots by immersing the entire pot in water and washing the soil from the plant roots. Each plant was visually assessed for root symptoms of the disease and infected plants were graded on a scale: 0, no swelling visible, to 3, severe swelling on lateral and/or taproot (Buczacki et al. 1975). Observations for phytotoxicity were made every second day after transplanting.

RESULTS

No treatment had a significant effect on plant survival (Table 2) but marginal leaf chlorosis and necrosis was observed on the first true leaves of all treatments containing boron. Only three of the chemical treatments (thiophanate-methyl, thiophanate-methyl + boron and thiophanate-methyl + sulphur) significantly increased fresh shoot weight when compared with the untreated inoculated control and despite the presence of the pathogen gave yields not significantly different from the uninoculated controls. Thiophanate-methyl either alone or in combinations appeared to be superior to tolclofos-methyl though the latter when used with napropamid gave yields equal to some thiophanate-methyl treatments. Neither of the two herbicides significantly affected shoot weight and when the trace elements were incorporated a significant increase was obtained only in those two-way combinations where thiophanate-methyl was present with either boron or sulphur.

All 75 plants in the inoculated controls were diseased. Fifteen chemical treatments gave a significant reduction in the percentage of plants infected. These included all nine treatments containing thiophanate-methyl, the two herbicide/trace element combinations containing trifluralin with either boron or sulphur and the four treatments where tolclofos-methyl was used with napropamid, boron, napropamid + boron and napropamid + sulphur. The most dramatic reduction in disease incidence was obtained with the thiophanate-methyl + sulphur treatment, though this did not differ significantly from four of the other combinations of thiophanate-methyl with herbicides and trace elements.

Only eight treatments significantly reduced the severity of disease (as indicated by clubroot grade) on infected plants. These treatments were among those which were effective in reducing disease incidence and included thiophanate-methyl alone, seven combinations of thiophanate-methyl with the herbicides and trace elements, and the three-way combination tolclofos-methyl + napropamid + sulphur. Only in three of the effective treatments, thiophanate-methyl alone, thiophanate-methyl + boron and thiophanate-methyl+ sulphur was a reduction in disease severity accompanied by a reduction in disease incidence and increased fresh shoot weight. The remaining five treatments while reducing incidence and severity of disease did not significantly increase fresh shoot weight.

The combination thiophanate-methyl + sulphur gave the greatest fresh shoot weight but this was not significantly better than when thiophanate-methyl was used alone however, as noted above, the incidence of disease was

Table 2

Effect of soil incorporated chemical treatments on clubroot levels and shoot weight of 7 week old Chinese cabbage plants

Treatment	Plant survival (%) *	Fresh shoot weight (g)	Diseased plants (%) *	Clubroot grade (max 3) on diseased plants only
Control uninoculated	100.0 a	3.29 a	0.0	0.00
Control inoculated	100.0 a	1.73 efgh	100.0 a	3.00 a
Thiophanate-methyl	97.2 a	3.08 abc	65.8 defg	2.26 bcd
Tolclofos-methyl	100.0 a	1.37 h	93.2 abc	2.61 abc
Trifluralin	100.0 a	1.46 fgh	84.0 abcde	2.73 abc
Napropamid	96.0 a	2.41 bcde	89.4 abcd	2.56 abc
Boron	100.0 a	1.71 efgh	90.6 abcd	2.55 abc
Sulphur	98.6 a	1.11 h	98.6 ab	2.83 ab
Trifluralin + boron	96.0 a	1.09 h	76.0 bcde	2.57 abc
Napropamid + boron	97.2 a	1.09 h	83.6 abcde	2.64 abc
Trifluralin + sulphur	96.0 a	1.18 h	77.8 cdef	2.75 abc
Napropamid + sulphur	93.4 a	1.50 fgh	84.4 abcde	2.42 abcd
Thiophanate-methyl + trifluralin	100.0 a	2.30 cdefg	33.2 gh	2.02 cd
Thiophanate-methyl + napropamid	97.2 a	2.49 abcde	79.3 cdef	2.27 abcd
Thiophanate-methyl + boron	97.2 a	2.69 abcd	50.8 fgh	1.73 d
Thiophanate-methyl + sulphur	100.0 a	3.24 ab	32.0 h	1.77 d
Thiophanate-methyl + trifluralin + boron	96.0 a	1.51 fgh	72.8 cdef	2.41 abcd
Thiophanate-methyl + napropamid + boron	95.8 a	1.98 defgh	62.0 efgh	2.11 bcd
Thiophanate-methyl + trifluralin + sulphur	97.2 a	1.43 gh	66.6 cdef	2.20 bcd
Thiophanate-methyl + napropamid + sulphur	100.0 a	1.74 efgh	33.2 gh	1.74 d
Tolclofos-methyl + trifluralin	96.0 a	1.23 h	89.0 abcde	2.39 abcd
Tolclofos-methyl + napropamid	98.6 a	2.34 cdef	70.2 cdef	2.36 abcd
Tolclofos-methyl + boron	89.4 a	1.61 efgh	74.2 cdef	2.28 abcd
Tolclofos-methyl + sulphur	97.2 a	1.65 efgh	89.2 abcd	2.55 abc
Tolclofos-methyl + trifluralin + boron	96.0 a	1.26 h	84.6 abcde	2.36 abcd
Tolclofos-methyl + napropamid + boron	98.6 a	1.45 fgh	65.4 cdef	2.42 abcd
Tolclofos-methyl + trifluralin + sulphur	93.2 a	1.25 h	91.6 abcde	2.53 abc
Tolclofos-methyl + napropamid + sulphur	94.6 a	1.84 defgh	75.0 bcde	2.19 bcd

Mean values followed by the same letter are not significantly different from each other (Duncan's Multiple Range Test $P = 0.05$, df108).

* The data in this column were transformed for analysis.

greatly reduced. When boron was used with thiophanate-methyl an increase in fresh shoot weight was obtained but disease incidence and severity were not superior to thiophanate-methyl alone. The two-way combinations of thiophanate-methyl + boron and thiophanate-methyl + sulphur did not differ significantly from each other in any parameter examined. Tolclofos-methyl used alone gave neither greater fresh shoot weight nor a reduction in disease when compared with the inoculated controls and in the combinations using that chemical, only tolclofos-methyl + napropamid + sulphur reduced disease severity. That treatment also reduced disease incidence but fresh shoot weight was not increased. Tolclofos-methyl + napropamid increased shoot weight when compared with tolclofos-methyl used alone but was not significantly different from napropamid alone.

Used alone the two herbicides did not differ from each other in regard to disease incidence or severity though napropamid gave increased fresh shoot weight. This trend was maintained when the herbicides were used with tolclofos-methyl. A comparison between these herbicides when used in conjunction with thiophanate-methyl shows that trifluralin gave greater reduction in disease incidence. In contrast, in the combinations with thiophanate-methyl + sulphur it was napropamid which gave the greater reduction in the percentage of plants affected. No significant difference between the efficacy of boron and sulphur was recorded either when used alone or in combinations.

DISCUSSION

This is the first reported attempt at the integration of three agrochemical groupings for the control of P. brassicae. The treatments were evaluated under conditions which were particularly favourable to the pathogen since Chinese cabbage is acknowledged as being one of the most susceptible of all crucifers (Crute et al. 1980), temperature and moisture were maintained at an optimum level for P. brassicae development and a uniform and high level of inoculum was employed. It is therefore likely that treatments which prove successful under these conditions would offer the possibility of enhanced control of clubroot disease in environmental conditions less favourable to the pathogen, such as may be found under field conditions.

The rates chosen for the herbicides and trace elements were those which had previously given some reduction in clubroot disease without phytotoxicity. It is interesting to record that no treatment which included materials from those three agrochemical groups, either alone or more particularly when in combination, exhibited major phytotoxicity symptoms. In all treatments which included boron (250 mg/kg), however, slight phytotoxicity was recorded in the early growth of plants.

No significant reduction in the disease or increase in yield was recorded when a herbicide or trace element was used alone. For the herbicides, this result is in contrast to the reduction in disease incidence reported by Buczacki (1973) for trifluralin and the enhanced disease control reported by Robak and Dobrzanski (1978) for trifluralin or napropamid when these herbicides were used alone. The latter authors reported that when these herbicides were applied with the fungicide carbendazim the control of this disease was in some cases more efficient compared to carbendazim used alone. The present results do not demonstrate increased disease control when napropamid was added with the related MBC fungicide thiophanate-methyl. However, when trifluralin was combined with thiophanate-methyl, a significant reduction in disease incidence was recorded and the addition of napropamid to tolclofos-methyl resulted in an increase in fresh shoot weight when compared to tolclofos-methyl alone. The combinations trifluralin with boron or sulphur significantly reduced disease incidence but without reducing severity or increasing fresh shoot weight. This is in contrast to napropamid which did not reduce disease expression when applied with either trace element.

Boron or sulphur applied alone did not reduce disease incidence or severity but previous reports of the effects of these trace elements originated from field trials where disease pressure, under such conditions, could be considered less severe than in the present experiment. However, when in combinations, these trace elements had a significant impact on the disease. Boron combined with trifluralin significantly reduced disease incidence and boron or sulphur combined with thiophanate-methyl dramatically reduced disease severity and incidence.

The most successful fungicide was thiophanate-methyl. Its effect in reducing disease incidence and severity when used alone at 250 mg/kg confirms the report of Buczacki (1983). In the two-way combinations, with the trace elements, it integrated well giving increased fresh shoot weight, reducing disease incidence and severity when compared to the infected control. The most successful reduction in the effects of clubroot disease was given by the thiophanate-methyl + sulphur treatment. The addition of sulphur resulted in the lowest level of plants diseased, the highest fresh shoot weight and one of the lowest scores for disease severity of any treatment. When boron was applied with thiophanate-methyl it did not differ significantly from when sulphur was added with this fungicide but it gave a lower fresh shoot weight and a higher number of diseased plants. It is significant that, despite the presence of the pathogen, thiophanate-methyl alone or in combination with either trace element gave yields comparable to the uninoculated controls.

At the rate employed in this study tolclofos-methyl failed to control the disease when applied alone and only in the combination with napropamid did a worthwhile increase in yield and reduction in disease incidence occur. The rate at which tolclofos-methyl was used in this experiment was half that which the present authors had previously found effective (Doyle & Clancy 1986).

Adding herbicides did not enhance the efficacy of thiophanate-methyl and furthermore their addition to thiophanate-methyl + boron or sulphur resulted in a significant reduction in fresh shoot weight in all but the one combination where napropamid was applied with thiophanate-methyl + boron. This reduction in fresh shoot weight, when compared with thiophanate-methyl plus trace element treatments but without herbicides, may be interpreted as a phytotoxic effect from the combination of agrochemicals since disease incidence and severity did not differ significantly from those treatments with herbicide added. This possibility requires further investigation, since the herbicides when used alone or in combination with thiophanate-methyl or either trace element did not result in a fresh shoot weight significantly less than the infected control. Further investigations into the effects of these herbicides on control methods for clubroot disease are urgently required as both herbicides, either alone or in combination, are used extensively in brassica production and frequently in field trials where fungicide treatments are being evaluated. It is evident that they influence disease expression and possibly the effectiveness of a fungicide or fungicide plus trace element treatment in controlling P. brassicae. Buczacki, in 1973, while reporting good control of clubroot using trifluralin at 50 mg/kg, also noted an increase in disease at low concentrations of herbicide and since the rate at which the herbicides were employed in this study was equivalent to ten times that normally used in brassica production the effects of a range of application rates, from that recommended for weed control up to the rate used in this study, should be examined.

The combination of a fungicide (zineb) and the trace element sulphur for control of clubroot disease has been extensively reported in Russian literature (Polyakov et al. 1975, Vytskii 1979, Vytskii et al. 1979, Asyakin 1981, Vladimirskaya et al. 1981). The possibility of such a combination has largely gone unexplored in western research. The results of this study demonstrate the successful integration of a fungicide, in this case thiophanate-methyl, and trace elements, especially sulphur, in controlling clubroot disease. Their success under such high disease pressure offers the possibility of enhanced disease control in field crops. The efficacy of thiophanate-methyl plus boron or sulphur under field conditions is presently under evaluation.

REFERENCES

Anon. (1985) Studies of chemicals for control of Plasmodiophora brassicae (Clubroot). Research Investigations and Field Trials, School of Agriculture Aberdeen, 83/84, 25-27.

Antonova, G.G.; Shestiperova, Z.I.; Shuvalova, G.V. (1975) Effect of root feeding with boron and manganese in reducing damage by cabbage clubroot (In Russian). Referativnyi Zhurnal 4, 1224. In: Review of Plant Pathology 54, 5611.

Asyakin, B.P. (1981) The effectiveness of immunizing fungicides in increasing the resistance in cabbage to Delia brassica Bouche and Plasmodiophora brassicae Wor. (In Russian). All-Union Research Institute for Plant Protection, 121-125. In: Review of Plant Pathology 63, 5187.

Buczacki, S.T. (1973) The effects of trifluralin and related dinitroaniline herbicides on clubroot of brassicae. Annals of Applied Biology 75, 25-30.

Buczacki, S.T. (1983) Glasshouse evaluation of NK 483 and other fungicides for clubroot control. Tests of Agrochemicals and Cultivars No. 4 (Annals of Applied Biology 102, Supplement), 48-49.

Buczacki, S.T.; Toxopeus, H.; Mattuch, P.; Johnston, T.D.; Dixon, G.P.; Hobolth, P.A. (1975) Study of physiologic specialization in Plasmodiophora brassicae: Proposals for attempted rationalization through an international approach. Transactions of British Mycological Society 65, 295-303.

Crute, I.R.; Gray, A.R.; Crisp, P.; Buczacki, S.T. (1980) Variation in Plasmodiophora brassicae and resistance to clubroot disease in brassicas and allied crops - a critical review. Plant Breeding Abstracts 50, 91-104.

Doyle, O.P.E.; Clancy, K.J. (1986) Glasshouse evaluation of fungicides for control of clubroot. Tests of Agrochemicals and Cultivars No. 7, (Annals of Applied Biology 108, Supplement) 50-51.

Dunin, M.S.; Vladimirskaya, M.E.; Utkina, N.I.; Vytskii, V.A. (1981) Gene centres of plant origin and induced immunity from disease (In Russian) Zashchita Tastenii 3, 22-26. In: Review Plant Pathology 1980 61, 455.

Il'ina, M.N. (1979) The effectiveness of immunizing fungicides in the control of cabbage clubroot (In Russian) All. Union Academy of

Agricultural Sciences, 117-121. In:*Review of Plant Pathology* *1980* *59*, 5442.

Johnston, T.D. (1968) Clubroot in Brassicae: A standard inoculation technique and the specification of races. *Plant Pathology* *17*, 184-187.

Polyakov, I.; Vladimirskaya, M.E.; Il'ina, M.N. (1975) Control of cabbage clubroot (In Russian). *Zashchita Rastenii* *4*, 39-40. In:*Review of Plant Pathology* *54*, 5613.

Robak, J.; Dobrzanski, A. (1978) The control of club-root (*Plasmodiophora brassicae* Wor.) on cabbage seedlings with trifluralin and napropamid herbicides. *Acta Agrobotanica* *31*, 151-158.

Vladimirskaya, M.E.; Utkina, N.I.; Vytskii, V.A. (1981) The effectiveness of chemical induction of cruciferae to the complex of harmful organisms (In Russian). *All-Union Research Institute for Plant Protection*, 91-98. In: *Review of Plant Pathology* *63*, 5186.

Vytskii, V.A. (1979) Control of clubroot of crucifers (In Russian). *Zashchita Rastenii* *6*, 34. In: *Review of Plant Pathology* *60*, 1119.

Vytskii, V.A.; Lukovnikova, G.A.; Savelenko, Yu. P. (1979) The effectiveness of immunizing fungicides in the control of clubroot of turnip in the Leningrad region. (In Russian). *All-Union Academy of Agricultural Sciences*, 133-138. In: *Review of Plant Pathology* *59*, 5443.

SESSION 8B

INSECTICIDE RESISTANCE: CURRENT INCIDENCE AND COUNTER-MEASURES

CHAIRMAN	DR J. P. FISHER
SESSION ORGANISER	DR I. DENHOLM
INVITED PAPERS	8B-1 to 8B-3

EVALUATION OF EXISTING RESISTANCE-MANAGEMENT STRATEGIES AGAINST ARTHROPOD PESTS OF COTTON

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ABSTRACT

In recent years, nationwide resistance-management strategies in Zimbabwe, Egypt and Australia have successfully overcome existing resistance problems on cotton and prevented further outbreaks in some key pests. These strategies rely heavily on pragmatic assumptions regarding the efficacy of counter-measures and the biology of pests; they relate little to theoretical models of resistance management whose tenets have so far not been experimentally appraised. We examine the motivations, philosophies and logistics of these and other successful control programmes on cotton, and outline scope for improvements in the methodology of resistance management and the counter-measures of existing and future resistance-countering strategies.

INTRODUCTION

Insecticide resistance is neither inevitable nor invincible. Nationwide resistance-management strategies in Zimbabwe, Egypt and Australia have for the last few years successfully overcome existing resistance problems on cotton and prevented further outbreaks in some key pests.

These measures have now been in force long enough to appraise their achievements and limitations. We propose therefore to examine the motivations, philosophies and logistics underlying these and other pest management strategies, how they relate, if at all, to theoretical concepts of resistance management, and to outline areas where scientific inputs can improve the efficacy of existing control programmes.

EXISTING STRATEGIES FOR MANAGING INSECTICIDE RESISTANCE

Most existing large-scale management strategies were initiated on cotton because this crop, of major importance to many countries and virtually impossible to grow economically without continuous control of arthropod pests, has suffered more than most from the ravages of insecticide resistance.

Zimbabwe

In 1973/74 Zimbabwe implemented the first nationwide strategy following the discovery not only that *Tetranychus cinnabarinus* and *T. lombardinii* showed widespread, strong and persistent resistance to dimethoate, but that few of the 100+ translaminar acaricides tested in a major screening programme could control these dimethoate-resistant mites (Duncombe 1973, Blair 1986). To prevent further resistance in acarines, which by then had become major pests of cotton, the decision was taken to rotate the use of the few remaining effective acaricides in space and time. The country was divided into three regions containing approximately the same acreage of cotton, which were to use acaricides of different chemical groups for two consecutive seasons, change to the next group for the following two years, and so on. This results in a four year gap before each group of compounds is re-used in the same region, a period of non-exposure to allow reversion should any resistance arise.

This voluntary strategy has now been in force for the last ten years, and has been closely adhered to by growers and pesticide distributors alike. Since its inception there has been no new resistance recorded in mites on cotton.

A similar rotation strategy is being established to counter resistance in *T. evansi*, an introduced pest only recently recorded on tobacco. However, since *T. evansi* has not been detected on cotton and *T. cinnabarinus* does not infest tobacco it will not be necessary to coordinate the two rotation schemes.

Following the introduction of pyrethroids in 1979/80, voluntary preventative steps have also been taken to forestall resistance to pyrethroids in the two major bollworms infesting cotton, *Heliothis armigera* and *Diparopsis castanea* (Brettell 1983, Blair 1986). The three winter months (June-August) are designated a pyrethroid-free season nationwide, and cotton growers are advised to use pyrethroids only during a defined period of not more than nine weeks that coincides with maximum flowering of cotton when both bollworms occur in damaging numbers on the crop. Similar restrictions are recommended for all other annual crops. On cotton it is recommended that only pyrethroids (fenvalerate, flucythrinate and fluvalinate) known to suppress *Tetranychus* populations be used. Outside the pyrethroid treatment season the two bollworms are controlled separately with endosulfan (*Heliothis*) or carbaryl and thiodicarb (*Diparopsis*), and acarines with acaricides currently recommended for the region.

As yet there has been no recorded resistance of bollworms to pyrethroids.

<u>Egypt</u>

In Egypt, a country whose economy depends to a large extent on cotton, the state-directed resistance management programme is specifically designed to prevent or delay pyrethroid resistance in the Egyptian cotton leafworm, *Spodoptera littoralis,* the most destructive indigenous cotton pest (Sawicki 1986). In 1978, the Egyptian Cotton Protection Committee released synthetic pyrethroids for agricultural use with instructions that they were to be restricted to a single application per year, only against *S. littoralis*, only on cotton, and forbade their use on all other crops. To ensure rigid application of these instructions, pyrethroids were released to farmers from state-run distribution centres only in mid-July when *S. littoralis* was peaking on cotton, and in quantities sufficient for only a single application to the cotton fields. Simultaneously the Cotton Protection Committee introduced a programme for controlling other cotton pests that involved integrated pest management as well as orthodox pest control methods.

Prior to 1978 cotton pests had been controlled by several applications of the same insecticide not only on cotton but on all other crops. This had resulted in the rapid and sequential development of resistance, and by the mid 1970s the cotton leafworm resisted most compounds available for its control. The management system introduced by the Egyptians not only stopped this treadmill but actually reversed it. Since 1978 there has been no new case of resistance to insecticides by cotton pests, and *S. littoralis* has lost much of its resistance to previously-used compounds. Thus this preventive strategy of compulsory moderation introduced and enforced by state authorities appears to have worked satisfactorily so far.

Australia

In October 1983 the Australians introduced a voluntary resistance-countering strategy after synthetic pyrethroids had failed for the first time against *H. armigera* at Emerald in Queensland earlier that year. To prevent further pyrethroid resistance outbreaks, the corresponding departments of the Governments of New South Wales and Queensland devised a strategy that banned pyrethroids from Emerald, and restricted their use elsewhere to only three applications during a 42-period that coincided with the peak attack of cotton by *H. armigera* (Forrester & Cahill 1984 and in press). After this period any pyrethroid-resistant survivors would be controlled by alternative insecticides or ovicide/larvicide mixtures of at least two chemical groups which are not believed to cross-resist pyrethroids. Simultaneously restrictions were placed on the use of endosulfan because of previous resistance to this cheap and popular insecticide, and putative cross-resistance between pyrethroids and endosulfan.

This strategy has now been in force in NSW and Queensland for three growing seasons and has been followed with virtually total compliance throughout the two States, although it is not popular with some sections of the agrochemical industry, heavily dependent on sales of pyrethroids, and many grain growers who feel that the strategy only benefits cotton growers. This universal compliance with very severe restrictions on the use of a very effective and highly prized group of insecticides in this very entrepreneurial society refutes the often-quoted argument that voluntary nationwide resistance management cannot work in a free economy because of the conflicting interests and rivalries between the parties involved.

This curative strategy aimed at containing resistance genes already present at detectable frequencies throughout the country is considerably more ambitious than the preventive measures applied at the onset of pyrethroid use in Zimbabwe and Egypt. To date it has worked well; the increase in pyrethroid resistance at the end of each spray season has been countered by a subsequent decline to levels enabling effective control with these compounds the following year.

MOTIVATIONS FOR, AND DESIGN OF EXISTING STRATEGIES

Existing resistance-management strategies for cotton pests have two important features in common:

(i) all were implemented in countries with a documented history of insecticide resistance on cotton, and first-hand experience of the damage that can ensue, and

(ii) all involve large-scale temporal and sometimes spatial restrictions of the use of pesticides they are intended to protect.

In the past, the sequential build-up of multiple resistance by *S. littoralis* in Egypt not only diminished the supply of insecticides still effective against this pest, but had on several occasions had disastrous effects on the country's economy. Similarly, the collapse of cotton growing in the Ord Valley of Western Australia in the early 1970s precipitated by the rise to prominence of DDT-resistant *H. armigera*, and subsequent failures with DDT in the Namoi Valley, NSW, amply demonstrated to all parties the destructive power of insecticide-resistant pests. The discovery in Zimbabwe of up to 1000-fold resistance to dimethoate in *Tetranychus* spp. extending to other little-used compounds not only motivated the acaricide strategy but compensated for the lack of documented failures with Lepidoptera. To quote J.H. Brettell (unpublished report): "We had learnt our lesson ten years earlier with red spider resistance and cross-resistance, and were determined not to be caught out again with bollworms and the pyrethroids".

It is also no coincidence that all three strategies involving Lepidoptera were introduced to contain resistance to pyrethroids which, by common consent, are the nearest we have to ideal insecticides with unprecedented effectiveness against these pests. In Zimbabwe the advent of the pyrethroids enabled for the first time both major species of bollworm to be controlled with a single insecticide, thus avoiding the need for mixtures often expensive and difficult to apply.

Despite being formulated independently under different agricultural and socio-economic systems, the three strategies are based on the same belief, namely that pyrethroid resistance is best prevented or delayed by severe restrictions on the use of this class of compound on cotton and other crops, and by reliance on other chemical groups for pest control during the less critical periods of the cotton season. The limited use of pyrethroids reduces the length of the selection period, and non-pyrethroids enable the control of selected larvae. Hence the three strategies are based on the concept of resistance management by restricted exposure to the selector and insecticide rotation. Furthermore, the insistance on regular scouting, particularly in Zimbabwe and Australia, and the discouragement of spraying on a calendar basis further reduces exposure by decreasing the overall number of sprays. Thus the overall emphasis of the three strategies is on a reduction in the total number of treatments, coupled with rotation. So far this has worked successfully both as a preventive measure, and as a curative strategy for the management of resistance.

AN ALTERNATIVE PHILOSOPHY - PEST MANAGEMENT WITH INSECTICIDES IN FRENCH-SPEAKING AFRICA (FSA)

It is interesting to compare existing pyrethroid-resistance strategies with the unified approach to cotton pest management that has so far successfully controlled cotton pests without eliciting resistance in 11 French-speaking countries of Africa, south of the Sahara (Cauquil 1985).

This simple but rigid programme, specifically designed to enable peasant farmers to control the pest complex on cotton, relies on the use of a single insecticide formulation, applied at regular intervals throughout the whole cropping season. The formulation always contains a pyrethroid to control bollworms, and in each country the number and strength of other less persistent ingredients (usually one or two organophosphorus compounds) reflects the effectiveness of these a.i.s against the most prevalent local pests. Once started the treatments (4-5/season on average) are applied by calendar dates, without deviation, and irrespective of pest status, degree of infestation, or size or age of the crop.

This programme was conceived to control cotton pests in the simplest and most effective way possible. It makes no direct concessions for managing resistance and dispenses with regular scouting, rotations or restrictions on the use of particular compounds, considered too complex to teach or administer effectively. Thus the philosophy behind the FSA approach contrasts markedly with that of existing resistance-management strategies yet, fortuitously, has had the same effect. As yet there have been no reports of control failure on cotton throughout FSA, despite the proven ability of *H. armigera* to develop resistance on crops continuously treated with pyrethroids, e.g. tomatoes in Senegal (Cauquil 1985).

COMPARISON OF EXISTING PROGRAMMES WITH THEORETICAL MODELS OF RESISTANCE MANAGEMENT

Is it possible in the light of theoretical models of resistance management and their recommendations to explain why these diametrically-opposed philosophies (FSA vs. the rest) have succeeded so far in arresting or preventing control failure with pyrethroids through resistance?

Counter measures that have been appraised by models relate either to the tactical use of single compounds through management by 'moderation' or by 'saturation' (sensu Sutherst & Comins 1979, Georghiou 1983) or to the use of two or more insecticides alternately in rotation or simultaneously in mixtures. The major conclusions of these models can be summarised thus:

(i) Management by moderation, which aims to reduce the selection pressure by the use of low application rates, short-lived residues and/or strategic timing of treatments, should delay resistance to some extent and requires far less stringent conditions than management by saturation, aimed at overcoming existing resistance (R) mechanisms by killing R insects. The latter tactic demands that pesticides are applied uniformly at high rates, and that residues either decay rapidly or are maintained at close to full strength. It is therefore only feasible in very limited cases.

None of the programmes described in this paper complies neatly with either type of management. Scouting in Australia and Zimbabwe improves the strategic timing of applications, but the use, by necessity, of long-lived residues and of low acceptable pest thresholds militates against moderation. Likewise to achieve the expected level of control Australians use application rates up to three times higher than those in Zimbabwe and FSA.

The FSA programme at first sight seems closer to management by saturation since sprays are timed to maintain the effectiveness of the most persistent component of the mixture, i.e. the pyrethroid. However in practice the coverage is so variable and rates so weak that they are very unlikely to fulfil the most important tenet of the saturation approach, namely the uniform deposition of doses of insecticide strong enough to kill R insects.

(ii) According to theoretical models, the rotation of two or more insecticides in succession is likely to result in the appearance of resistance to these compounds only marginally slower than if each individual insecticide were to be used continuously until resistance impaired control (Curtis, in press). This rather surprising conclusion, which holds regardless of the initial frequency of R genes, depends on complex genetic assumptions regarding the competitive ability of R insects in the absence of the selector(s). Rotations seem more promising only when R genes confer a significant disadvantage in this respect, but in general population genetics theory provides little support for alternating chemical sprays.

Thus the most important assumption of existing preventive and curative strategies on cotton has little theoretical support. If this conclusion of models is correct, the apparent successes in Zimbabwe, Egypt and Australia may merely reflect an increase in the calendar life of pyrethroids through temporal restriction on their use and not an extension of their absolute period of effectiveness.

(iii) However, models agree that insecticide mixtures can greatly delay resistance compared with the continuous use of single compounds (Curtis 1985, Mani 1985). Even so this statement is a gross oversimplification, because substantial delays are only achieved when the active components of the mixture are equally effective against the target pest(s), have equal environmental persistence, and when resistance to at least one of the compounds, and preferably both, is extremely rare.

Since some or most of these stipulations are not met by formulations used in FSA, it is unwise to relate the success of the FSA programme to the use of mixtures.

Thus it is clearly not possible to identify unambiguously the operational parameters responsible for the efficacy of present programmes because they relate so little to the recommendations of models for managing resistance. This is further compounded by the scarcity of empirical work to support the tenets of existing theoretical and practical counter-measures.

Likewise there are few data to assess the impact of ecological and genetic parameters on resistance in present-day strategies. The generally held assumption that the pyrethroid strategies provide ample opportunity for susceptible individuals that escape exposure in unsprayed refugia to dilute resistant populations is challenged by events in Thailand where pyrethroid resistance is uniformly strong and persistent in spite of a vast reservoir of *H. armigera* on the unsprayed maize crop (Collins 1986). Moreover, even in Australia where pyrethroid resistance in *H. armigera* has been studied most actively for the last three years there is still very little known about the number and dominance of resistance genes, the nature of the mechanism(s), the cross-resistance characteristics and the impact of the strategy on the dynamics of R genes.

Hence all existing resistance management strategies are basically models of population genetics in which common-sense and pragmatism replace scientific input. We have thus no reliable scientific basis on which to hypothesize why, in spite of fundamentally different approaches and their failure to comply with available theory, existing strategies and the FSA programme have managed to converge on the same net result, i.e. good pest control without resistance. This is a most unsatisfactory state of affairs.

SCOPE FOR IMPROVEMENTS TO EXISTING STRATEGIES

In the light of the foregoing analysis, we foresee that for the immediate future any new large-scale preventive and curative strategies that are applied will be in the agricultural sector and probably be of similar design to those already in force. They are most likely to succeed where:

(i) resistance threatens the economic fabric of a state or country; especially where there have already been well-documented failures through resistance, preferably catastrophic to convince all parties of the need for a strategy,

(ii) there is a good entomological infrastructure to formulate, introduce, supervise and (where applicable) enforce the strategy,

(iii) the distribution and sale of agrochemicals can be controlled by either the private or public sector, and

(iv) all parties are prepared to abide by the measures to ensure the continued efficacy of control programmes.

We also foresee that such strategies will primarily involve rotations, severe restrictions on the use of lead compounds and related compounds, and be limited to the control of a single key pest.

It is therefore necessary to appraise very thoroughly the tenets of this approach through experimentation and much more realistic models. Our work at Rothamsted has convinced us that whether strategies turn out to be a belated and ad hoc response to uncontrollable events, or a series of rational decisions based on the least questionable and most effective tactics will depend on substantial developments in two key areas of research:

(i) the development of a reliable methodology to measure the extent of the problem and the pest's response to the counter-measures applied, and

(ii) the determination of the efficacy of putative counter-measures in delaying or preventing resistance.

Methodology

The methodology must include:

(i) reliable sampling procedures to provide representative estimates of the frequency of resistant individuals in the field (Dennehy & Granett 1984),

(ii) laboratory assays that correlate the effectiveness of the discriminating dose(s) with the effectiveness of the application rate(s) in the field against S and R insects, and

(iii) means of determining the 'critical' frequency at which resistance impairs control in the field (Denholm *et al.* 1984, Dennehy in press).

The serious lack of insight into the statistical constraints that affect the accuracy of monitoring, especially of incipient resistance, has even prompted Roush & Miller (1986) to suggest that where diagnostic tests do not provide an accurate estimate of the frequency of R individuals it may be better to adopt prophylactic resistance management on the assumption that resistance will develop rather than rely on inaccurate resistance monitoring.

Most resistance-monitoring techniques record absolute changes in the frequency of R individuals or the level of resistance, but provide little guidance as to implications of such changes for control in the field. This is true even in Australia, where despite careful monitoring it is still not possible to correlate the response to discriminating doses in the laboratory with the efficacy of the field rate against S and R larvae of *H. armigera.* Existing internationally-recommended bioassay procedures are not satisfactory for this purpose.

Appraisal of counter-measures

It is also essential to determine which of the counter-measures presently in use (rotations, mixtures, restrictions, etc.), all based on varying the operational parameters defining insecticide treatments, do lead to substantial delays in resistance. This appraisal must include:

(i) the development of experimentation to validate potential counter-measures disclosed by current strategies and mathematical models, and

(ii) the development of more relevant and specific models that take into account the severe practical constraints of a pest management programme (Denholm 1986).

It is also essential to obtain a clearer understanding of the bionomics and population dynamics of major pests, since this is the scenario on which the strategy is imposed. This can of course be studied before the onset of any resistance problem, unlike specific details of the genetics and mode of action of resistance mechanisms which can only be investigated once resistance becomes apparent. Thus although knowledge of the nature of the resistance and its genetics may improve the workings of a strategy, it cannot play a role in its initial formulation.

We foresee that once the most important parameters determining resistance are identified, they will be incorporated into computer programs such as SIRATAC (Hearn & Da Roza 1985), a cotton pest management system used in Australia to minimise reliance on insecticides and predict when sprays are essential to maintain target yields. With such powerful decision-making tools, resistance should become increasingly manageable and pest control failures such as experienced in Thailand (Collins 1986) and elsewhere may hopefully become a thing of the past.

REFERENCES

Blair, B.W. (1986) Strategies to minimize resistance in arthropod pests to acaricides and synthetic pyrethroid insecticides in Zimbabwe. Proceedings IVe Congres sur la Protection de la Sante Humaine et les Cultures en Milieu Tropical, 222-227.

Brettell, J.H. (1983) Strategies for cotton bollworm control in Zimbabwe. Zimbabwe Agricultural Journal 80, 105-108.

Cauquil, J. (1985) La protection des cottoniers contre leur ravageurs en Afrique francophone au sud du Sahara: Principe et evolution des techniques. Coton et Fibres Tropical (Quarterly Review of l'Institut de Recherches du Coton et des Textiles Exotiques (I.R.C.T.)) 1985 (4), 187-202.

Collins, M.D. (1986) Pyrethroid resistance in the cotton bollworm, *Heliothis armigera* - a case history from Thailand. Proceedings 1986 British Crop Protection Conference - Pests and Diseases (in press).

Curtis, C.F. (1985) Theoretical models of the use of insecticide mixtures for the management of resistance. Bulletin of Entomological Research 75, 259-265.

Curtis, C.F. (in press) Genetics aspects of selection for resistance. Proceedings of a Society of Chemical Industry Symposium - Fundamental and Practical Approaches to Combatting Resistance held at the University of Southampton, July 15-17, 1986.

Denholm, I. (1986) Operational counter-measures for resistance: theory and practice. Proceedings IVe Congres sur la Protection de la Sante Humaine et des Cultures en Milieu Tropical, 239-246.

Denholm, I.; Sawicki, R.M.; Farnham, A.W. (1984) The relationship between insecticide resistance and control failure. Proceedings 1984 British Crop Protection Conference - Pests and Diseases 2, 527-534.

Dennehy, T.J. (in press) Decision making for managing pest resistance to pesticides. Proceedings of a Society of Chemical Industry Symposium - Fundamental and Practical Approaches to Combatting Resistance held at the University of Southampton, July 15-17, 1986.

Dennehy, T.J.; Granett, J. (1984) Monitoring dicofol-resistant spider mites (Acari: Tetranychidae) in California cotton. Journal of Economic Entomology 77, 1386-1392.

Duncombe, W.J. (1973) The acaricide spray rotation for cotton. Rhodesia Agricultural Journal 70, 115-118.

Forrester, N.W.; Cahill, M. (1984) Field evaluation of an insecticide management strategy for the control of pyrethroid resistant *Heliothis armigera*. Proceedings 1984 Australian Cotton Growers Research Conference, Toowoomba, Queensland, 88-96.

Forrester, N.W.; Cahill, M. (in press) Management of pyrethroid-resistant *Heliothis armigera* in Australia. Proceedings of a Society of Industry Symposium - Fundamental and Practical Approaches to Combatting Resistance held at the University of Southampton, July 15-17, 1986.

Georghiou, G.P. (1983) Management of resistance in arthropods. In: Pest Resistance to Pesticides G.P. Georghiou and T. Saito (Eds), Plenum, New York, pp. 769-792.

Hearn, A.B.; Da Roza, G.D. (1985) A simple model for crop management applications on cotton (*Gossypium hirsutum* L.). Field Crops Research 12, 49-69.

Mani, G. (1985) Evolution of resistance in the presence of two insecticides. Genetics 109, 761-783.

Roush, R.T.; Miller, G.L. (1986) Considerations for the design of insecticide resistance monitoring programs. Journal of Economic Entomology 79, 293-298.

Sawicki, R.M. (1986) Countering resistance to pyrethroid insecticides. Agriculture Business Worldwide July issue, 81-85.

Sutherst, R.W.; Comins, H.N. (1979) The management of acaricide resistance in the cattle tick *Boophilus microplus* (Canestrini) (Acari: Ixodidae), in Australia. Bulletin of Entomological Research 69, 519-537.

INSECTICIDE RESISTANCE - WHAT IS INDUSTRY DOING ABOUT IT?

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ABSTRACT

The agrochemical industry has a vital interest in prolonging the useful life of its products. In this context, delaying or preventing the onset of resistance is very important, as is "managing" resistance when it has finally occurred. To this end pyrethroid manufacturers set up the Pyrethroids Efficacy Group (PEG) in 1979. On a wider basis, under GIFAP, the Insecticide Resistance Action Committee (IRAC) was formed in 1984. The structure, functions and interrelations of these bodies are described, together with current activities. PEG has undertaken resistance monitoring studies in Turkey and Thailand, and the results have been shared with the respective governments; PEG is also embarking on a programme of applied research into resistance mechanisms. IRAC is currently working to establish a short list of priority resistance cases for industry involvement. All this work must lead towards the implementation of practical strategies for resistance management in the field; the difficulties in that are considerable and can only be overcome by close cooperation between governments, the agrochemical industry and growers.

INTRODUCTION

It is a commonly-held view that the agrochemical industry does not care about the development of resistance to its products; that resistance means a company can sell more tonnes as farmers increase usage rates; and that resistance to one group of compounds gives industry a chance to introduce a new group at a higher price.

The truth is very different. Agrochemical companies are very concerned about the length of life of their products. With the cost of developing a new compound now well in excess of £20 m, and with a projected life in the market place of at least ten years, it can be disastrous if resistance begins to cause field failure of the product after say three or five years of use. Furthermore the task of finding any single new insecticide - let alone an entirely new group of compounds which would be free from cross-resistance - is so difficult today that a company is doing well to introduce a new one every five years.

In these circumstances it is clearly in the interests of each company, and therefore the industry as a whole, to take practical steps to delay the onset of resistance and if possible to prevent it from ever resulting in field failure. By the same token, where resistance has become established the industry has a pressing need to develop use programmes which control the pest while still including the products involved. Because of this, agrochemical companies have for some years now devoted considerable efforts to the "management" of insecticide resistance. This paper briefly describes how those efforts have become organised, industry's recent activities in the area, and where those activities are leading.

WHAT IS INDUSTRY DOING?

Pyrethroids Efficacy Group

An opportunity for cohesive action came in the late seventies with the advent of the synthetic pyrethroids. Here was an entirely new chemical group, which several companies would be marketing, and which in terms of efficacy, safety and cost-competitiveness far outstripped existing insecticides. It was clear that the pyrethroids would be the new generation of molecules that would dominate the market place for at least a decade, probably much longer. However, it was equally clear that this would certainly not happen unless reliable use rates were established, a careful watch on tolerance/resistance development was maintained, and, where appropriate, steps were taken to minimise the risk of such resistance arising and leading to field failure.

In 1979, the pyrethroid manufacturers established a group of technical representatives known as the Pyrethroids Efficacy Group (PEG). PEG's function was to produce technical recommendations to extend the life of pyrethroids by minimising the risk of resistance arising. In the mid 1980's, now that pyrethroid resistance has developed in a number of localities around the world, PEG is heavily involved in the management of such cases. As part of these activities PEG has funded resistance monitoring studies in Thailand and Turkey; the results of these studies have been presented to the respective Governments and have helped greatly in clarifying the degree and extent of resistance. The work in Turkey is continuing; the results of the study in Thailand are referred to later in this paper.

These cases exemplify two of the key roles now played by PEG: to establish the true facts about field failure of products as caused by resistance, and to assist governments in developing strategies for dealing with the resistance problem in pyrethroids. This involves close cooperation between PEG, government officials, and the growers' associations, which in itself is not an easy thing to achieve. However, without the full cooperation of all parties no resistance management strategy can be implemented satisfactorily.

This leads us to another key role of PEG: to improve understanding between all the partners in agriculture - governments, growers and industry. Typical of this activity is the Open Meeting convened in June 1986 by PEG at El Centro, in the Imperial Valley, California. This full-day meeting was attended by 26 people: government legislators, senior academic researchers, local pest control consultants, and representatives of the pyrethroid manufacturers from PEG. This forum proved to be extremely valuable in exchanging information across such a wide spectrum of participants. More importantly, the Meeting was able to agree on a joint statement about the status of resistance to pyrethroids of *Heliothis* spp on cotton in the USA. This was a matter of controversy, particularly after events late in the 1985 season, and PEG attached considerable weight to the need for agreement as a baseline to understand 1986 developments.

It is also of course a matter of great practical importance to the pyrethroid companies that false rumour of resistance should not be allowed to become 'received wisdom' and thus to diminish pyrethroid usage unnecessarily. At the same time, to ignore the first warning signs of resistance would be foolish in the extreme. The full text of the El Centro joint statement will be published elsewhere but the main conclusions were as follows:

1. *Heliothis zea* shows no significant tolerance to pyrethroids in the USA.
2. *Heliothis virescens* has had no reports of significant tolerance in East and Central USA. Tolerance levels are higher in the West, eg the low desert valleys of Southern California and Arizona. There has so far been field failure against *H. virescens*, attributable to resistance, in only one area of the USA - Uvalde, Texas in 1985. In that instance, exceptional factors operated: late replanting after a hailstorm caused late cotton development; and late-season populations of *H. virescens* were at a high level. These late-season populations are normally less susceptible to pyrethroids.

The meeting concluded that it was impossible to say if the field failure would have occurred in the absence of these factors, or whether these factors caused the problem by allowing a dangerous underlying level of tolerance to be manifest as field failure. However, it was agreed that the Uvalde incident should be regarded as a first warning sign of danger.

As mentioned earlier, PEG undertook a monitoring study in Thailand in 1985, in collaboration with the Thai government. This work is reported in detail in the companion paper to this in the Proceedings (Collins 1986), and only the main conclusions are repeated here.

First, the study confirmed that pyrethroid resistance (PyR) is present among *Heliothis* in cotton with a mean population R-factor of around 50-fold. All three populations sampled were highly heterogeneous and a range of resistance genotypes is implicated; pyrethroid-susceptible individuals were isolated from the heterogeneous field population and their presence indicates a potential for resistance management. Interestingly, however, PyR had not declined following a relaxation of selection pressure during the non-cotton season, when the *Heliothis* continue to breed in maize. Evaluation of the

Thai resistant strains at Reading University demonstrated cross- or multiple-resistance to DDT and the carbamates, but not to organophosphates or endosulfan.

Aided by this work, the Thai Department of Agriculture has developed a set of recommendations involving product alternation, to reduce selection pressure.

In addition to the activities described above, PEG has now committed itself to sponsoring research aimed at understanding the mechanisms of resistance and their heritability. This research will have a strong practical orientation, intended to give a scientific basis to resistance management strategies; it is planned that work will commence in 1987.

Insecticide Resistance Action Committee

In 1984 a larger body was formed under the umbrella of GIFAP (the International Group of National Associations of Manufacturers of Agrochemical Products). This body was designated the Insecticide Resistance Action Committee, IRAC, and although individual representatives are drawn from agrochemical companies, each one attends IRAC meetings as a representative of the respective National Association, and not a particular company. This provides an important legal framework within which IRAC can operate, responding to GIFAP through the Agriculture Committee.

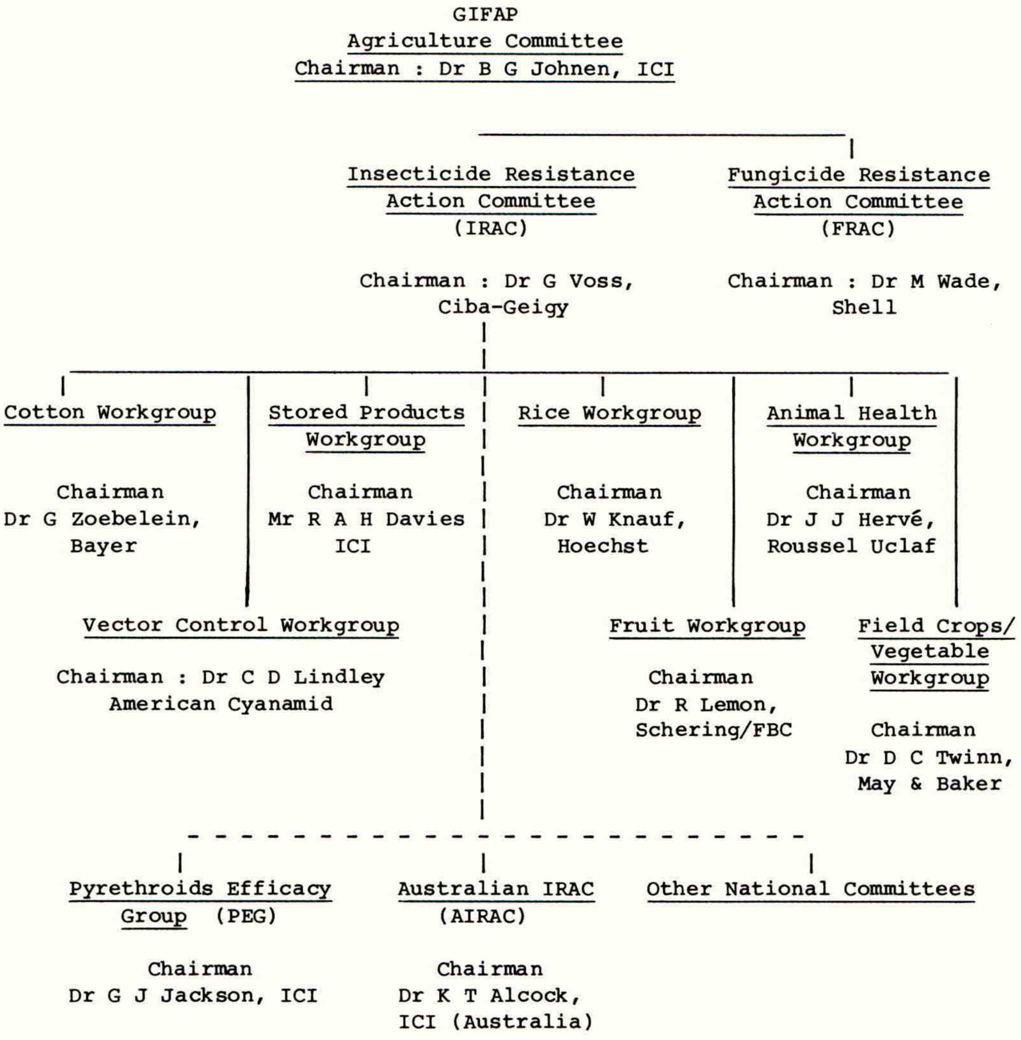
IRAC's role parallels that of GIFAP's Fungicide Reistance Action Committee (FRAC) which was founded in 1981; IRAC's remit is to:

- Provide expert advice to GIFAP on all technical and scientific matters relating to insecticide and acaricide resistance
- Develop relationships with non-industrial researchers in the field of insecticide resistance
- Advise and assist GIFAP in preparing and presenting an industry view on resistance
- Co-ordinate industry efforts to prolong the life of insecticides and acaricides by defining and recommending appropriate technical strategies to combat resistance.

To fulfil this role, IRAC has established a number of workgroups to deal with specific resistance problems in different crops. These workgroups are responsible for evaluating real and suspected control failures caused by insecticide/acaricide resistance, and for proposing strategies to retard or prevent the development of resistance.

In an interesting futher development, 1985 saw the inauguration of several national action committees, such as the Australian Insecticide Resistance Action Committee, AIRAC; these national committees work in close liaison with IRAC itself. Another move was the incorporation of PEG as an 'independent sub-group' of IRAC: the chairman of PEG now sits on IRAC as a representative of pyrethroid manufacturers, i.e. in a different capacity from other IRAC members in that he does not represent a National Association.

Thus, there now exists a coherent organisation within the agrochemical industry for tackling resistance problems; the structure of this organisation is shown in Figure 1.



GIFAP
Agriculture Committee
Chairman : Dr B G Johnen, ICI

Insecticide Resistance Action Committee (IRAC)
Chairman : Dr G Voss, Ciba-Geigy

Fungicide Resistance Action Committee (FRAC)
Chairman : Dr M Wade, Shell

Cotton Workgroup
Chairman
Dr G Zoebelein, Bayer

Stored Products Workgroup
Chairman
Mr R A H Davies
ICI

Rice Workgroup
Chairman
Dr W Knauf, Hoechst

Animal Health Workgroup
Chairman
Dr J J Hervé, Roussel Uclaf

Vector Control Workgroup
Chairman : Dr C D Lindley
American Cyanamid

Fruit Workgroup
Chairman
Dr R Lemon, Schering/FBC

Field Crops/ Vegetable Workgroup
Chairman
Dr D C Twinn, May & Baker

Pyrethroids Efficacy Group (PEG)
Chairman
Dr G J Jackson, ICI

Australian IRAC (AIRAC)
Chairman
Dr K T Alcock, ICI (Australia)

Other National Committees

Figure 1. Organisation of Industry's Resistance Committees

IRAC's main concern since its formation has been to sort out, from the great mass of reports of resistance (confirmed or otherwise), those cases of true resistance that are a matter of priority for industry involvement, and also those cases where there is potential for an important resistance problem in the future. This has proved a large and complex task but is nearing completion, and IRAC will soon be able to move towards targetted actions on specific cases.

Resistance Management Programmes

As mentioned earlier, a major function of bodies such as PEG and IRAC is to assist governments in developing programmes for "managing" resistance, and to assist in the implementation of such programmes.

An excellent example is the system adopted by the Egyptian Government for the control of *Spodoptera littoralis* and other pests in cotton. In this programme, which was developed in consultation with Dr R M Sawicki of Rothamsted, pyrethroids are used only for one spray round, in the earlier part of the season, and are not permitted to be used in any crop other than cotton. This programme, which was strongly supported by PEG from the outset, is almost certainly responsible for the fact that R-factors to pyrethroids in *S. littoralis* have not increased significantly since their introduction; pyrethroids today are still fully effective on the target pests in Egyptian cotton.

In Australia, government entomologists developed a 'window' strategy (Forrester & Cahill 1986) for the management of insecticide resistance in *Heliothis armigera*; PEG's endorsement of the strategy was an important factor in persuading the local company subsidiaries to adopt it. The establishment of the Australian strategy, however, illustrates the difficulties faced in this area. Sawicki (1986) discussed the pre-requisites for introducing such a strategy; although these factors were present in the Australian case, still there were major problems in persuading all parties to cooperate.

In the cases of Thailand and Turkey some of Sawicki's pre-requisite factors are absent, particularly that ..... 'all parties are prepared to abide by the impositions and restrictions to ensure the continued effectiveness of this compound'. The plethora of products, distributors and cotton growers in Thailand will make it very difficult to implement the government's programme, while in Turkey it would be difficult to prevent leakage of pyrethroids into cotton from other crop sectors.

Thus the implementation of resistance management programmes presents great difficulty which must not be under-estimated. However, the agrochemical industry is now geared to the overall requirement of resistance management; it has put in hand the necessary development and monitoring work and is about to embark on a programme of applied research. The challenge of the next five years will be to devise and implement effective management strategies, both curative and preventative.

REFERENCES

Collins, M.D. (1986) Pyrethroid resistance in the cotton bollworm, *Heliothis armigera* - a case history from Thailand. *Proceedings of the 1986 British Crop Protection Conference - Pests and Diseases* (in press).

Forrester, N.W. and Cahill, M. (1986) Insecticide management strategy for control of resistant *Heliothis armigera* (Hübner) in Australia. *Rapports Generaux et Communications du IV Congres sur la Protection de la Sante Humaine et des Cultures en Milieu Tropicale, Marseille* 248-252.

Sawicki, R.M. (1986) Countering resistance to pyrethroid insecticides. Agriculture Business Worldwide (in press).

RESISTANCE MANAGEMENT STRATEGIES IN AUSTRALIA : THE HELIOTHIS AND "WORMKILL" PROGRAMMES

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ABSTRACT

The aims, scientific bases and implementation of the *Heliothis* and "Wormkill" strategies are discussed. The strategies are compared with reference to their limitations and possible future modifications. It is concluded that for each strategy the aims are broader than that of management of resistance to a specific chemical. Furthermore, although the population biology of the pests is more clearly defined in the "Wormkill" programme, both strategies are based on general, rather than specific, models of the evolution of resistance. Each strategy is seen as making a positive contribution to the agricultural ecosystem in which it is used.

INTRODUCTION

Management strategies are devised to delay the onset of resistance or as a response to an existing resistance problem. The challenge of the latter is often necessary to galvanize theory into practice but, in either case, a number of steps can be recognised in the design of a practical strategy. Initially, possible alternatives can be identified from general theoretical models (e.g. Georghiou & Taylor 1977, Comins 1977, Georghiou 1983, Curtis 1985) and then the most appropriate chosen with due consideration to the population biology of the pest(s), the relative fitness of different resistance genotypes and the possibility of cross-resistance to other chemicals. As some (most) of this information may be unavailable, the strategy must be sufficiently robust to accommodate the assumptions made in the absence of these data.

This paper compares two strategies currently in operation in Australia. The first, for *Heliothis*, arose directly from field failure of synthetic pyrethroids and is implemented across a number of regions and crops under the sphere of governmental influence utilising extension and significant peer pressure by growers. The second ("Wormkill"), implemented by extension, aims to control nematodes in sheep with possible benefits at the level of an individual property on the Northern Tableland of New South Wales.

THE HELIOTHIS STRATEGY

After a series of field failures to synthetic pyrethroids in the Emerald Irrigation District of Queensland (1982/83) and the confirmation of resistance in *H. armigera* (Gunning *et al*. 1984) a strategy was devised to prevent further control failure. This strategy was influenced by the experience of previous resistance in *H. armigera* to DDT (Wilson 1974, Goodyer *et al*. 1975. Kay 1977, Goodyer & Greenup 1980) and endosulfan (Kay *et al*. 1983) before pyrethroids were introduced. More enlightened growers gained benefit from a simple chemical alternation approach. That approach used endosulfan on cotton, primarily against *H. punctigera*, until late

The cyclical pattern of resistance frequency could change if more extensive use of pyrethroids led to a significant contamination of susceptible populations. At present there is little knowledge about the effective size of populations of _H. armigera_ which breed outside irrigated or dryland cropping areas and the relative importance of gene flow between each. The answer to this question will probably be gained by the end of 1986 as the frequency of resistance at the end of last season in the Namoi was about 45%. If this again declines to below 10% it seems reasonable to assume that gene flow is effectively unidirectional at this stage.

The relationship between gene frequency and field failure is elusive. It has yet to be demonstrated that pyrethroids are an efficacious selecting agent for resistance at all life-stages and under conditions of good application. Estimates of resistance are not easily related to gene frequencies. A discriminating dose must not only kill all susceptibles but also no heterozygotes or homozygotes. This cannot be the case in the "discriminating dose" used in _H. armigera_ resistance because of the low resistance factors observed. We estimate that over 50% of putative resistant homozygotes are killed at the dose used to estimate the frequency of resistance (J.C. Daly, unpublished data). The use of resistance factors _per se_ to discuss the severity of resistance is an inexact substitute for an estimate of gene frequencies. J.C. Daly & J. Fisk (unpublished data) have demonstrated that selective mortality is not occurring in larvae less than four days old under commercial applications of insecticide nor does it occur in most larvae exposed to leaves which had been sprayed more than five days previously. Forrester's observations (Table 1.) of an immediate rise in the frequency of resistance with the use of pyrethroids are consistent with selection of adults but not of larvae. However, field failures only occur in larvae if the number of survivors after spraying exceeds an economic threshold. In these terms, it is obvious that the presence of a high frequency of resistance is not a sufficient condition for a field failure: larvae four, or more, days old must be present in high densities for field failure to occur. An alternative strategy simply aimed to avoid field failures with pyrethroids would be not to recommend the use of pyrethroids on such populations; that is substitution of an alternate chemical or the use of mixtures.

The strategy as the best model for reducing selection pressure on pyrethroids

Different aims of the strategy may be in conflict. For instance reduction of pyrethroid and endosulfan use (points 1 and 2) may be at variance with points 4 and 5, the need to manage all pests on crops and to use pyrethroids at peak flowering.

If the strategy's sole aim was to reduce selection pressure for pyrethroid resistance in _H. armigera_, then the insecticide should be used against pests of crops when _H. armigera_ was of secondary importance, such as in spring. Alternative chemicals, organophosphates or endosulfan, would be used when _H. armigera_ was the primary pest.

With the current strategy, however, the period of pyrethroid use was deliberately chosen to coincide with the most damaging infestations of _H. armigera_, at peak flowering when this species is very abundant. On crops other than cotton, it is normally medium sized larvae that are sprayed and not neonates. Also in cotton, the economic threshold for larvae and eggs recommended by the SIRATAC pest management programme are higher later in the season. If these conditions occur during stage 2 they are likely to maximise the selection pressure for resistance because selective mortality occurs in medium sized larvae (J.C. Daly & J. Fisk, unpublished data).

An argument can also be made for delaying the use of pyrethroids until later in the field season as their use can create outbreaks of secondary pests such as mites. Furthermore the longer residual not only has more severe effects on beneficial insects but also is of little value when the crop is rapidly growing as the positioning of the pests on the plant limits their exposure to residues in these circumstances.

These comments need to be balanced against the argument for using pyrethroids during peak flowering. When the crops are most vulnerable to economic damage a highly efficacious and cheap insecticide is required to guarantee control. It is believed that pyrethroids are the only insecticide in Australia which can satisfy this requirement. Thus, it is necessary to maintain resistance at low frequency to maximise the efficacy of pyrethroids at peak flowering.

THE "WORMKILL" PROGRAMME : DEFINITION AND EVALUATION

The scientific basis of this strategy again depends on general models of the evolution of resistance, in this case to anthelmintics (Donald & Waller 1982). This literature has developed in parallel to that of other resistance disciplines. In general, resistance is believed to be contained by

1. reducing selection pressure through minimizing the use of anthelmintics (management by moderation)
2. using narrow-spectrum anthelmintics to reduce selection on non-target species (management by moderation)
3. using doses above the LD_{100} of resistant individuals (management by saturation)
4. rotation of chemicals (management by multiple attack)
5. integrating control systems that are not exclusively dependent on anthelmintics (management by moderation).

There is evidence to support each of these propositions although their relative importance to, and ease of implementation in, control programmes is a matter of debate (Martin 1985, Dash *et al*. 1985). As Australia leads the world in its history of generating resistance to anthelmintics (Le Jambre *et al*. 1979, Martin 1985) it is not surprising that a strategy to manage resistance was necessary even in the absence of clear cut information on each of the 5 points.

Two genera of nematodes, *Haemonchus contortus* and *Trichostrongylus* spp., are parasites of sheep on the Northern Tableland of New South Wales (Anderson *et al*. 1978). Historically, control was normally achieved by 3 treatments (August, November, February) of broad-spectrum anthelmintics. However, while this is providing effective control of *Trichostrongylus*, control of *H. contortus* has only been possible with increasingly more frequent treatment. It has been found, however, that 3 treatments (at the above times) with closantel, while having no effect on infections by *Trichostrongylus* spp., provide effective control of *H. contortus* (Dash *et al*. 1985).

In this light the "Wormkill" programme was introduced in 1984 after extensive consultation between CSIRO and the New South Wales' Department of Agriculture and Pasture Protection Board. It aims to limit the number of treatments with broad-spectrum anthelmintics to reduce further selection by these chemicals, particularly in Trichostrongylus colubriformus where increased frequency of treatment seems certain to result in multiple resistance becoming widespread (Dash et al. 1985). To maintain susceptibility to closantel in H. contortus is also critically important. Management of susceptibility is the best way to manage resistance!

Recommendations were made as to the timing of treatments, the anthelmintic to be used and the age of the animal (Table 2.). These recommendations integrate minimal drench usage with appropriate treatment times defined with respect to the population biology of the nematodes and by periods of infection. For instance, lambs may receive an extra broad-spectrum anthelmintic treatment in April to control infections with Trichostrongylus spp. if such infections increase enough during February to April to warrant this (Dash et al. 1985).

TABLE 2.

Treatment schedule for the "Wormkill" programme

Time of Treatment	Adult Sheep and Hoggets		Lambs	
	Closantel	Broad-spectrum anthelmintic	Closantel	Broad-spectrum anthelmintic
August	+	+	*	*
November	+	+	+	+
February	+	+	+	+
April	-	-	-	+

\+ chemical in drench, - chemical not given
* August is the pre-lambing treatment

Adapted from Dash et al. 1985

The strategy was rapidly adopted by 74% of producers even in its first year (Dash et al. 1985) and has resulted in a significant reduction in the frequency of treatment for worms. It was implemented through extension associated with wide coverage by the national rural press and on radio. This was followed by direct mailing to all producers, public meetings and field days. Reinforcement is being continued through newsletters and the media.

The programme has been expanded from the Northern Tablelands to operate in eight Pasture Protection Board Districts. Its rapid acceptance by producers may reflect previous uncertainty regarding methods of worm control that is overcome by the straightforward recommendations of

"Wormkill". The impact of successful extension should not be underestimated nor should the fact that with nematode management an individual producer is largely responsible for the scale of his resistance problems as the vagility of the pest is limited. There is therefore more flexibility in the programme than for the Heliothis strategy.

It should be noted the programme depends on closantel providing control of H. contortus. Resistance to this chemical would render "Wormkill" inoperative. As the closantel "decay curve" is more akin to that of an insecticide than to that of a traditional anthelmintic, the selection intensity for resistance may be severe (McKenzie 1985). Thus, considerable thought is being devoted to the timing and frequency of closantel treatment to minimize any response (Dash et al. 1985, Barton, unpublished data). This may lead to modifications of the basic programme in the future. For instance, it seems possible control of H. contortus may be achieved by two, perhaps one, treatments per year if current infestation patterns continue (Anderson pers. comm.). Any modifications will be based on the experience gained as the resistance status of individual properties is extensively monitored as part of the assessment of the programme.

A COMPARISON OF THE TWO STRATEGIES

The Heliothis and "Wormkill" resistance management strategies differ in a number of critical ways:

1. Their foundation depends on different general philosophies of resistance management. The Heliothis strategy is based on the alternation of chemicals supplemented by the use of mixtures, "Wormkill" solely on the use of mixtures.
2. The Heliothis strategy applies to a large number of broad acre agricultural industries, each of which may differ in its needs for insecticide control of pests, whereas the "Wormkill" programme applies to a single industry, sheep.
3. Insecticide usage in broad-acre crops can lead to infestations of secondary pests, whereas anthelmintics are only directed against primary pests.
4. Widespread compliance is not essential for the success of "Wormkill" because of the limited vagility of nematodes. The Heliothis strategy is very dependent on a high rate of compliance given the polyphagous, highly migratory nature of H. armigera.
5. Compliance with the Heliothis strategy is voluntary in New South Wales and under minimal supervision in Queensland. However, the decision making process is one of a guided democracy by governmental departments, after consultation with grower organisations, consultants and chemical companies enhanced by effective extension to, and peer pressure between, growers. Such tight management of the strategy may be necessary in Heliothis because those who benefit the most from the strategy may not be those who suffer the greatest expense. All users of pyrethroids are not equally likely to experience field failures nor are they likely to be as financially damaging to all growers. Compliance seems almost complete. In the "Wormkill" programme, the emphasis has been on education through extension. Not all farmers have complied with it, yet those who do see a personal benefit through a reduction in costs of treatment.

Both strategies are based on general models of the evolution of resistance but have aims more expansive than the management of resistance to a particular pesticide. Each has made a significant contribution to the industries they serve.

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REFERENCES

Anderson, N.; Dash, K.M.; Donald, A.D.; Southcott, W.H.; Waller, P.J. (1978) Epidemiology and control of nematode infections. In: The Epidemiology and Control of Gastrointestinal Parasites of Sheep in Australia Donald, A.D.; Southcott, W.H.; Dineen, J.K. (Eds), Melbourne: CSIRO Division of Animal Health, pp. 24-51.

Anon. (1983) Pyrethroid resistance. Australian Cotton Grower 4(3), 4-7.

Comins, H.N. (1977) The development of insecticide resistance in the presence of migration. Journal of Theoretical Biology 64, 177-197.

Curtis, C.F. (1985) Theoretical models of the use of insecticide mixtures for the management of resistance. Bulletin of Entomological Research 75, 259-265.

Dash, K.M.; Newman, R.L.; Hall, E. (1985) Recommendations to minimise selection for anthelmintic resistance in nematode control programmes. In: Resistance in Nematodes to Anthelmintic Drugs Anderson, N.; Waller, P.J. (Eds), Sydney: CSIRO Division of Animal Health, Australian Wool Corporation, pp. 161-169.

Donald, A.D.; Waller, P.J. (1982) Problems and prospects in the control of helminthosis in sheep. In: Biology and Control of Endoparasites Symons, L.E.A.; Donald, A.D.; Dineen, J.K. (Eds), New York: Academic Press, pp. 157-186.

Forrester, N.W. (1984) Pyrethroid resistance situation for the Namoi and lower Gwydir Valleys, N.S.W. Australian Cotton Grower 5(1), 35.

Forrester, N.W. (1985) Pyrethroid resistance strategy - retrospect and prospect. Australian Cotton Grower 6(3), 5-7.

Forrester, N.W.; Cahill, M. (1987) Management of insecticide resistance in Heliothis armigera (Hübner) in Australia. Pesticide Science (In Press).

Georghiou, G.P. (1983) Management of resistance in arthropods. In: Pest Resistance to Pesticides Georghiou, G.P.; Saito, T. (Eds), New York: Plenum, pp. 769-792.

Georghiou, G.P.; Taylor, C.E. (1977) Genetic and biological influences in the evolution of insecticide resistance. Journal of Economic Entomology 70, 319-323.

Goodyer, G.J.; Greenup, L.R. (1980) A survey of insecticide resistance in the cotton bollworm, Heliothis armigera (Hübner) (Lepidoptera: Noctuidae), in New South Wales. General and Applied Entomology 12, 37-39.

Goodyer, G.J.; Wilson, A.G.L.; Attia, F.I.; Clift, A.D. (1975) Insecticide resistance in Heliothis armigera (Hübner) (Lepidoptera: Noctuidae) in the Namoi Valley of New South Wales. Journal of Australian Entomological Society 14, 171-173.

Gunning, R.V.; Easton, L.R.; Greenup, L.R.; Edge, V.E. (1984) Pyrethroid resistance in Heliothis armiger (Hübner) (Lepidoptera: Noctuidae) in Australia. Journal of Economic Entomology 77, 1283-1287.

Kay, I.R. (1977) Insecticide resistance in Heliothis armigera (Hübner) (Lepidoptera: Noctuidae) in areas of Queensland, Australia. Journal of Australian Entomological Society 16, 43-45.

Kay, I.R.; Greenup, L.R.; Easton, C. (1983) Monitoring Heliothis armiger (Hübner) strains from Queensland for insecticide resistance. Queensland Journal of Agricultural and Animal Sciences 40, 23-26.

Le Jambre, L.F.; Royal, W.M.; Martin, P.J. (1979) The inheritance of thiabendazole resistance in Haemonchus contortus. Parasitology 78, 107-119.

McKenzie, J.A. (1985) Genetics of resistance to chemotherapeutic agents. In: Resistance in Nematodes to Anthelmintic Drugs Anderson, N.; Waller, P.J. (Eds), Sydney: CSIRO Division of Animal Health, Australian Wool Corporation, pp. 89-95.

Martin, P.J. (1985) Nematode control schemes and anthelmintic resistance. In: Resistance in Nematodes to Anthelmintic Drugs Anderson, N.; Waller, P.J. (Eds), Sydney: CSIRO Division of Animal Health, Australian Wool Corporation, pp. 29-40.

Murray, D.; Cull, P. (1984) Resistance strategy works at Emerald. Australian Cotton Grower 5(1), 22-25.

Wilson, A.G.L. (1974) Resistance in Heliothis armigera to insecticides in the Ord Irrigation Area, north Western Australia. Journal of Economic Entomology 67, 256-258.