Session 3A

Pesticides Residues - Concern or Complacency?

Chairman	Dr B Thomas
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Papers	3A-1 to 3A-4

THE FOOD SAFETY PARADOX -- PERCEPTION VS. REALITY

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ABSTRACT

While food scares have been around for more than a decade, it was the Alar hysteria of 1989 which caused consumer confidence in the food supply in the U.S. to plummet. But the fires of controversy burned so hot that consumers seem to have backed away from the issue, despite a continuing stream of alarmist reports from advocacy groups who try to advance their legislative agenda with a relentless pursuit of political toxicology. Regulatory agencies must continue to improve risk assessment methodology to fully restore public belief in the reality that the food supply is safer than ever in history.

"Do I dare eat a peach?"
-- T.S. Eliot

If T.S. Eliot had asked that question in the last five years or so, the answer might have been, maybe, maybe not. First, he may have had to ask himself: What's the chemical-of-the-week news on peaches?

If you had asked the average American consumer that question in February 1989, after the Natural Resources Defense Council (NRDC) released its report, *Intolerable Risk: Pesticides in Our Children's Food* (NRDC, 1989), the response would have likely been one of fear and confusion. The Natural Resources Defense Council is a 100,000-member environmental group considered one of the most powerful and successful in the U.S. Through litigation (it has more lawyers on its staff than scientists), testimony at legislative hearings, and publication of detailed studies, it has had a significant impact on regulatory policies and programmes at the national and state level. In its landmark pesticide report, it said that as many as one out of every 3,400 children between 1 and 5 years old could one day get cancer because of the pesticides they ate as young children. To support this prediction, the NRDC presented a "scientific" study--using assumptions that can most charitably be described as outside the mainstream. I call this kind of science "political toxicology," the use of science to pursue a political agenda. Political toxicology that links pesticide use in agriculture to food safety has been practiced for years to advance a legislative agenda, and the scare tactics that accompany it attract widespread public interest. Advocacy groups know it is easier for people to relate to something personal--the food they eat daily--rather than to more abstract or distant issues, such as the impact of pesticides on far-off rivers or unknown farm labourers. Advocacy groups are a business like any other. As Gregg Easterbrook, an environmental author and contributing editor to *Newsweek* magazine, said, a doomsday scenario is a "much better fund-raiser than guarded optimism" (Shaw, 1994c).

The flame kindled by the NRDC report was fanned into an inferno of controversy by an uncritical if not reverential presentation of its point of view on the highly popular television news magazine "60 Minutes," viewed by an audience of 40 million Americans. The result was a kind of hysteria I hope never to see again. Although the NRDC studied 23 pesticides used on 27 commodities, and discussed a variety of chronic and acute health effects, publicity from the NRDC and the "60 Minutes" piece focused on one chemical--Alar, one commodity--apples, and one outcome--cancer. Cancer was the obvious choice, the disease Americans worry about most, comparable to the fear Europeans have of birth defects. Even though heart disease kills 40% more Americans each year (500,000 vs. 700,000), cancer arouses a unique dread (Shaw, 1994a). It can be painful and crippling, slowly consuming your vitality--not to mention your life's savings. Chemicals with cancer-causing potential are regulated differently in the U.S. Cancer has its own politics and laws, its own mathematics of probability for risk assessments.

Alar was also a good choice for the NRDC despite the fact it was not highly toxic and was just used on one crop. It had been a focus of concern by the U.S. Environmental Protection Agency (USEPA) as a potential carcinogen. More to the point, the one crop it was used on was apples, which children consume in large amounts both as fruit and juice. We have a saying in America: "motherhood and apple pie," referring to issues that are close to the heart, and the heartland.

Of course, pesticides in general have long been an easy target. They are a broad category of products with unique distinctions from most other synthetic chemicals. They have been specifically developed to kill one pest or another, and unlike most other environmental poisons (which are usually byproducts of industrial processes), pesticides are deliberately introduced into the environment. Pesticides also have another distinct characteristic: they can be regulated. Scientists have identified several major cancer risk factors: dietary habits, excessive sunlight, and cigarette smoking. These risk factors are difficult if not impossible to regulate, with the possible exception of smoking, which has become a target of increasingly strict controls in the U.S.

Pesticides also suffer from a lack of perceived benefit. These days farming is typically portrayed as an "agribusiness" empire bent on indiscriminate pesticide use in pursuit of obscene profits to the detriment of farmworkers and the public. The farmers make the profit and the public bears the risk--that's the perception. Again, perception is not reality. Chemicals are costly inputs, used by farmers only when needed. The public benefits from an abundant, high-quality, low-cost supply of fruits and vegetables. Americans don't perceive this benefit because it has been nearly two generations since they have known anything else.

That the choice of targets was not accidental was made clear in October 1989 with the publication in the *Wall Street Journal* of an internal memorandum written by a public relations firm. The memo detailed the carefully orchestrated public relations campaign put together by the firm for the NRDC. The result was a very successful illustration of the impact of political toxicology. School districts throughout the United States pulled apples from school lunch menus. Sales of fresh apples, apple juice, and other apple products plummeted, reportedly costing the apple industry more than $100 million (Shaw, 1992b). There were congressional hearings, and calls for reform of the nation's pesticide laws. Alar was pulled off the market by its manufacturer, even as scientists assured the public of the safety of apples.

Not surprisingly, public confidence in the nation's food supply plummeted. The U.S. Food Marketing Institute (FMI) does an annual survey of these things. In January 1989, consumer confidence was a positive 81%. By August, it had dropped precipitously to 67% (Cook, 1989).

What was the reality? Certainly not that thousands of kids were going to get cancer. After the report was released, toxicologists in my Department looked at eight pesticides it analyzed. Using the best data and the most widely accepted scientific models, we found risks were from 10 to 100 times lower than the report estimated, and within acceptable limits. Britain's Advisory Committee on Pesticides also concluded that the risk of getting cancer from the small amount of Alar was minuscule (Shaw, 1994b).

An NRDC toxicologist made a presentation to my scientific staff in the spring of 1989 on the "Intolerable Risk" report. The report maintained and NRDC representatives continually stated how many people would actually get cancer from eating Alar-treated apples. However, the NRDC toxicologist explained that these statements were based on calculations never meant to represent actual occurrences of disease. The calculations were not the most likely risk values but were the standard, *theoretical*, upper-bound estimates of risk used by regulatory agencies worldwide to make risk management decisions. The wide margin of uncertainty that surrounds virtually all such numbers was ignored, along with all the assumptions that tend to overstate risk. Asked why theoretical numbers were given out as if they represented actual cancer projections, he explained, "They are easier to get across that way."

This is an illustration and the NRDC is not alone. The activist political agenda is to change the way pesticides are regulated. That's their big picture--get citizens to demand legislative change. However, on a day-to-day basis--the way most people live their lives--the reaction is usually not to sign up for a political action campaign. Instead, people may change their produce buying habits. Like T.S. Eliot, they begin to ask if they dare eat that peach or apple. Their perception is that food is unsafe. That isn't the reality. I am Director of the California Department of Pesticide Regulation (CDPR), part of the California Environmental Protection Agency. I administer the U.S.'s most comprehensive state programme to regulate the sale and use of pesticides, including product evaluation and registration, product quality testing, use enforcement, and environmental monitoring. California has the nation's largest programme to monitor fresh produce for pesticide residues. The programme goes back to 1926, when arsenic-based residues were the focus of concern and we took several hundred samples a year. Today, our multiresidue screens are capable of detecting more than 300 pesticides and their metabolites, and we test more than 12,000 samples annually of about 160 different kinds of fresh fruits and vegetables. We find few violative residues, and detections are generally well below the allowable levels (CDPR, 1991). In 1992, we took 7,319 samples from throughout the channels of trade in our Marketplace Surveillance Program. The results mirrored previous years. No residues were detected in 69 percent of the samples. Residues at less than 50 percent of the federally approved tolerance level were detected in 29 percent. Residues at 50 to 100 percent of tolerance were detected in less than 1 percent. Illegal residues comprised only 0.93 percent. Of these, most were pesticides not authorized for use on the commodity (usually the result of off-target drift). Only 0.2 percent had residues over the tolerance level. These results are even more significant because our enforcement sampling is not designed to produce data that are statistically representative of the residue situation for a particular pesticide or commodity. Sampling is weighted toward such factors as patterns of pesticide use and past monitoring results. Therefore, our results may be biased toward finding produce more likely to contain illegal residues than if samples were collected randomly.

CDPR also has a separate Priority Pesticide Program that concentrates monitoring on pesticides of toxicological concern. In this programme, we sample only crops known to have been treated with targeted pesticides. This provides accurate data on which to base estimates of dietary exposure. In 1992, we analyzed 4,776 samples in this program. We targeted 54 pesticide active ingredients and 72 commodities on which they were used. Even though 100 percent of the commodities were treated, there were detectable residues in less than 18 percent of the samples. Most of the detected residues were at less than 50 percent of tolerance. Six samples (0.12 percent) contained illegal residues.

The reality--that dietary residues are not a health threat--is further borne out by the U.S. Department of Agriculture's (USDA) Pesticide Data Program (PDP). Begun in 1991, the PDP goal is to provide an improved data base on trace levels of residues for more accurate dietary risk assessments (USDA, 1992). The vast majority of residues found are orders of magnitude below federal tolerances. In 1992, residues of 49 different pesticides were detected in approximately 60 percent of 5,750 samples. More than 55 percent of residues were below 0.10 parts per million, with 8.5 percent less than 0.01 ppm.

With its low minimum levels of detection (MDLs), the PDP has a higher percentage of detections than CDPR's enforcement-based Marketplace Surveillance Program. With precise data on actual residues, dietary risk assessments can be made using fewer risk-enhancing assumptions. Among those assumptions is that every non-detect is considered to be a residue level at a certain percentage of the MDL (usually one-half). CDPR compared estimates of exposure and margins of safety derived from both the USDA and CDPR databases. Because CDPR uses higher MDLs, the use of the CDPR database generally resulted in higher estimates of dietary risk. This is because the PDP data usually shows that the actual residue levels are lower than the arbitrary levels we assigned. In other words, the zeros have become smaller, and so has the risk.

However, findings of low residues have done little to dim the spectre of imminent hazard repeatedly raised by critics. The NRDC report of 1989 and similar reports from advocacy groups since then have focused not on the *levels* of residue present in food but on their simple *presence*. "When in doubt, keep it out" has been the activist position (Cook, 1989). There has been little if any acknowledgement by advocacy groups and less responsible media that risk is a reality that can be reduced and managed, but never eliminated. There is little recognition that *because* of (not *despite*) the uncertainties of risk assessment, risk managers make assumptions at every step of the process that tend to greatly overstate risk. Similarly, there has been little regard for the toxicological significance of pesticide residues in food. This is despite scientific advances that have given us a vanishingly small zero with levels of detection in our monitoring programs *routinely* down to the low parts per billion. The question should be not "is it present" but "what does it mean?"

That, unfortunately, has been difficult to explain to a public which has little knowledge of science or expertise to delve into the complex, equivocal art of risk assessment. The public generally believes that exposure to any chemical, no matter what the level, is a cause of concern. Regulatory agencies must bear some blame for that misconception. In our rush to regulate, we sometimes forget that risk assessment has its limits. It is not as precise or as absolute as we or the public would like it. On the one hand, advocacy groups speak definitively of incredible risk. Unfortunately for us, we cannot prove there is no risk. We have no definitive answers. The failure of regulatory authorities charged with protecting the food supply to provide sufficient reassurance to the public that they can eat a peach without fear has played a major role in undermining public trust.

Our very science is based on uncertainties and results in exaggeration. We test chemicals on rodents specially bred to develop cancer easily. We use huge maximum tolerated doses and assume they are predictive of what tiny doses do to humans. Our regulatory policies disregard scientists who say that the maximum tolerated dose overwhelms cellular systems, and that is what causes tumors. As a recent editorial in the U.S. journal *Regulatory Toxicology and Pharmacology* put it, "the fact remains that we have no definitive scientific tools for the assessment of prospective human cancer risks" (Anonymous, 1994). We have built an entire scientific and regulatory apparatus around risk assessment. Yet we cannot explain why saccharin and DDT produce tumors in rodents and show no carcinogenicity in tests on nonhuman primates, even following 22 years of ingestion (Thorgeirsson, *et.al.*, 1994). Clearly, we must find better ways to assess risk. The U.S. National Academy of Sciences (NAS) in a report issued in June 1993--a report spawned by the 1989 Alar hysteria--called for several new approaches to risk assessment. The NAS is a private, nonprofit society of scholars engaged in scientific and engineering research. Under the authority of a charter granted by the U.S. Congress in 1863, the NAS has a mandate to advise the federal government on scientific and technical matters. In its report on pesticides and children, the NAS focused on greater use of pharmacokinetics, development of biologically based models, and better methods to address exposure to multiple chemicals and multiple routes of exposure (NAS, 1993).

With release of the NAS report, California formed a committee of scientists and other specialists from state environmental and health agencies. Their job was to review the NAS findings and to evaluate how well state and federal pesticide programs protect children and infants from pesticides in the diet. The committee's report was released in May (Pesticide Exposure to Children Committee, 1994). Many recommendations are consistent with those of the NAS, while in some areas it made different recommendations, including those targeted at California's regulatory programs. The committee discussed at length whether it should address the safety of the food supply. It finally did so, saying: "The current California and federal pesticide regulatory systems adequately protect infants and children from risks posed by pesticide residues in the diet. However, there are potential areas for improvement of the pesticide registration and food safety programs."

To me that means, in other words, food is safe and regulatory agencies are doing a good job but could do better. For example, we have to get away from the maximum tolerated dose and find a testing method that is more indicative of normal exposures. We need more emphasis on physiologically based pharmacokinetic models that can reduce uncertainties in extrapolating from animal models. We need better data on the differential sensitivity of children and adults, and on the more subtle toxic effects that pesticides may cause. We need new ways to assess the effects of multiple chemical exposures, for example, effects that occur in concurrent exposure to multiple chemicals with similar mechanisms of action. We need much better food consumption data, especially for infants and children, and for populations of different cultural and ethnic backgrounds. Residue data needs to be more usable, and to do that the U.S. has started to put together a national computerized residue database.

The public is subject to manipulation by misinformation, and these enhancements will help us be more precise about safety. In our experience, with better numbers we typically find less risk, and can be more assertive about saying so. Regulators are learning their lesson. So, apparently, is the media. There are signs that they are beginning to acknowledge their role in fueling public fears by uncritical reporting of alarmist accounts, and by not reporting facts that mitigate a threat (Shaw, 1992a,b,c). Three months ago, 16 million television viewers nationwide watched a primetime ABC News special, "Are We Scaring Ourselves to Death?" In it, long-time consumer reporter John Stossel argued that media reports suggesting that "there's danger everywhere and it's all getting worse...just (aren't) true." A little embarrassed, he showed video clips of a younger Stossel giving dramatic and alarmist coverage to several environmental stories--and then told viewers how he would approach these stories differently now, to provide more context about magnitudes of risk. Stossel is part of a revisionist movement among an increasing number of journalists (among them, *Newsweek's* Easterbrook and Keith Schneider of the *New York Times*) who think that the media have needlessly frightened Americans with biased handling of many environmental issues (Shaw, 1994a).

I am cautiously optimistic in reporting that recent surveys have suggested that the pesticide food safety issue is old news. Public confidence in food is rebuilding slowly and new advocacy reports about pesticides have generated little publicity and even less attention. The apple industry is enjoying record sales. In a 1993 survey, only 20 percent of shoppers admitted to being influenced by the media when it comes to their opinions about fruits and vegetables. (It also may be that people are hesitant to admit being swayed by the media.) Of those that said the media influence them, the most frequent response (31 percent) was that the media made them more conscious about health. In this open-ended survey (with no choices provided), only 11 percent said that the media made them more aware of chemical use (Vance Publishing Co., 1993).

In its 1994 report (FMI, 1994) on consumer attitudes, the Food Marketing Institute asked what constituted the greatest "threats" to food safety. Forty-two percent of those surveyed volunteered spoilage as the primary threat. This is a sharp increase from only 19 percent in 1991. Lagging behind were "pesticide residues," volunteered by 14 percent of shoppers (down from 20 percent in 1991) and "chemicals," volunteered by 12 percent (down from 15 percent in 1991). The percentage volunteering concerns about pesticides and chemicals has been declining since 1990. Pesticides score higher when the question is about "health hazards," not threats to food safety, and the survey method is altered so that shoppers are read a list of items that may pose a health hazard in food (spoilage was not among the choices). When read this list (which includes livestock drugs, nitrites, irradiated food, and preservatives), consumers rate pesticides as the most "serious hazard." Seventy-two percent of those surveyed thought so in 1994. However, this is down significantly from 79 percent in 1993. It is also lower than 1988, the first year of the survey, when it was 75 percent, and lower than any year since. Why do so many consider residues a "health hazard" but not a "threat"? FMI explains the paradox by saying: "An item considered to be a serious hazard in and of itself, for example, might be seen as little or no threat because it is perceived to occur rarely or at very low levels in the actual food supply."

However, you don't need to look at surveys to see that concern over pesticides in foods has diminished in the U.S. This year, pesticides were the subject of two major prime-time television shows, a "Frontline" special on the nation's public television network and a "48 Hours" report on CBS. Both were highly critical of the U.S. pesticide regulatory program and contained sensationalistic segments full of harrowing information on the dangers of residues in food. The shows produced nary a ripple on the national consciousness.

Even more amazing was the Cheerios saga. In June, the U.S. Food and Drug Administration (USFDA) found illegal residues of the pesticide chlorpyrifos on General Mills oat products--including one of the nation's most popular breakfast cereals, Cheerios. The residues resulted from the unapproved use of chlorpyrifos on stored oats by an outside contractor. Cheerios tainted with illegal residues had been shipped--and eaten by consumers--for some months before the contamination was found. A USEPA evaluation found that the low residue levels did not present a health hazard. Release of information on this situation was handled well by USEPA, USFDA, and General Mills. (We have all learned our Alar lessons well, and no one in the regulatory business can ignore the importance of effective risk communication.) Nonetheless, many regulators expected this issue--involving a pesticide-contaminated cereal eaten each morning by millions of children--to explode into controversy. It has not, with very few stories in the media and little public comment. However, this is the same summer that we have been told by scientists that margarine is just as bad for your heart as butter. I think many consumers have tuned out.

Although consumers seem less interested at the moment in pesticides, I wouldn't go so far to say that they have full confidence in their food. Building faith takes time. So will improving risk assessment methodology so it moves out of the realm of art fully into science, less reliant on assumptions to accommodate so many uncertainties. I recently heard a physician say in a speech that risk assessment is the only thing that can make economics look like a science and though the audience laughed, there's truth there, too.

As we improve our science, public confidence will also increase. When we can do our work with more certainty, we can provide better assurance to the public as well. I hope it's only a matter of time when asking whether to eat Eliot's peach will be a question of whether it is ripe, and will it spoil my dinner? Safety will be a given.

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PESTICIDE RESIDUE SURVEILLANCE BY THE FOOD INDUSTRY

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ABSTRACT

Current public interests in pesticide use focus upon the residues remaining after the application of pesticides during crop production and after harvest during storage periods. Recent pesticide and food safety legislation in the UK and EU has put greater demands on the food industry regarding their responsibilities towards the safety and quality of foods. Primary production is recognised as an integral part of the food production chain, and it is becoming increasingly important that some form of quality assurance, including the demonstration of 'due diligence', is applied to the production and sourcing of primary agricultural food products. This paper outlines why the food industry in the UK is concerned with pesticide use and what is being done to monitor pesticide residues in food raw materials, and discusses the results of industry residue surveillance programmes.

INTRODUCTION

Pesticide residues in food crops

Pesticides have an important role to play in the production of food crops. They minimise losses due to pest, disease and weeds, and help provide high quality products on a year-round basis. The use of pesticides does, however, have other implications for the quality and safety of primary agricultural products. In this paper pesticide use in crop production only is considered.

Current interests in pesticide use by the food industry in the United Kingdom (UK) focus upon the residues remaining after application during crop production and after harvest during storage periods. A residue is "any pesticide found in a sample, including any specified derivatives such as degradation and conversion products, metabolites which are considered to be of toxicological significance" (Anon, 1993). Residues in food raw materials are defined for individual pesticides as maximum residue limits (MRLs). These are set on a statutory basis by the UK Government and the Council of the European Union (EU), and on an advisory basis by the Codex Alimentarius Commission, an international body jointly set up by the Food and Agriculture Organisation and the World Health Organisation.

The MRL is "the maximum concentration of a pesticide legally permitted in or on food commodities and animal feeds" (Anon, 1993). The concept of setting an MRL is that if a pesticide is used as authorised, i.e. according to good agricultural practice (GAP), the remaining residue in commodities should not exceed the MRL value. Although residues in foods derived from commodities that comply with the respective MRLs are intended to be toxicologically acceptable, the MRL is itself a trading standard and not a safety standard.

Pesticides are widely used in the production of the majority of commodities in the EU and the rest of the world. For consistent supplies of high quality products that are suitable for the fresh and manufactured food markets in the UK and other EU countries, the use of pesticides is an essential part of food crop production. In general, this use of pesticides is well accepted by the food industry and, if used as authorised, are safe. However, residues of pesticides in food raw materials are an important safety and quality consideration for the food industry, particularly with public perception that pesticide residues constitute a risk.

UK legislation on pesticide residues in food

Pesticide residue levels in certain foods are controlled in the UK by the Pesticides (Maximum Residue Levels in Crops, Food and Feeding Stuffs) Regulations 1994. The Regulations replace the Pesticides (Maximum Residue Levels in Food) Regulations 1988 and implement three Community Directives adopted since the 1988 Regulations were made. The majority of the MRLs set by the 1994 Regulations are taken from Community Directives, but some are additional national levels.

In the UK breach of national statutory residue levels is an offence under the Food and Environment Protection Act 1985 (FEPA), although it is submitted that such an offence can only be committed by persons who applied the pesticide. This Act contains a general defence of due diligence. For crops subject to Community Directives, the Regulations do more than specify MRLs; they also prohibit the putting into circulation of any relevant product where limits are exceeded, specify penalties, and confer enforcement powers corresponding to those in FEPA. A defence is provided where products are being exported to third countries, are being used in the manufacture of things other than foodstuffs, or are seeds for planting.

Levels of residues of pesticides in food not covered by the Regulations will continue to be controlled by the general provisions of the Food Safety Act 1990.

Before the 1994 MRL Regulations, the presence of pesticide residues in any food at any stage in the food chain above which may be considered acceptable could also constitute an offence under the Food Safety Act. However, at the time of writing, it is unclear to what extent this still applies. Nonetheless, in terms of current industry practices, it has been a guiding principle. Food fails to comply with food safety requirements if:

- it has been rendered injurious to health; or
- it is unfit for human consumption; or
- it is so contaminated that it would not be reasonable to expect it to be used for human consumption in that state.

Food may not be of the 'substance' demanded if it contains extraneous matter such as pesticide residues which, although not a safety issue, may prejudice the consumer.

The Food Safety Act contains a similar due diligence defence to that provided for under FEPA, but in modified form to take account of modern food manufacturing and distribution practices. It states:

> "... it shall ... be a defence for a person charged to prove that he took all reasonable precautions and exercised all due diligence to avoid the commission of the offence by himself or by a person under his control".

There is nothing which makes it a legal requirement for a food business to be able to satisfy the statutory defence; however, in reality it is essential that every food business should establish an adequate due diligence system. Positive steps to set up a system must be taken. All reasonable precautions means setting up a control system, and all due diligence means ensuring that it works. The word 'all' requires that if there is a precaution that can be reasonably taken, it must be done.

MONITORING OF PESTICIDE RESIDUES BY FOOD BUSINESSES

It is within the context of the above pesticide and food safety legislation that food businesses in the UK have been encouraged to monitor pesticide use and the residues remaining in the food raw materials. They have sought to achieve these aims by ensuring that GAP is followed, i.e. only approved pesticides are used in the approved manner in the production of food crops, and that the residues in the primary agricultural practice are within statutory limits. If there is no statutory limit for a pesticide, an advisory limit may be considered the presumptive standard in UK law.

In addition, some food businesses have sought to reassure consumers on food production methods in terms of food safety and environmental concerns. A notable initiative is the NFU - Retailers Integrated Crop Management (ICM) Protocols, developed jointly by the National Farmers Union and some major retailers in the UK (Anon, 1994). The aim of the protocols is to address the concerns and needs of consumers, retailers and growers for safe food of good quality at affordable prices. This is to be achieved by the application of scientifically-based good agricultural practices, with the emphasis on reducing, wherever possible, the use of pesticides, and involves the promotion of viable ICM systems and improved protection of the environment.

The legal considerations relate to crops produced in the UK and for produce sourced from other countries. In general, the controls and monitoring implemented for pesticides by food businesses are applied equally to wherever the product is sourced. In this context 'control' is used in the sense of quality assurance, not legal 'control' of pesticides. It is worth noting that a food business might reasonably be expected to be able to control and monitor UK grown produce more effectively in terms of due diligence as it is more practical and reasonable to do so. However, this does not remove the requirement to control and monitor produce sourced elsewhere.

Food businesses have sought to satisfy the statutory defence by establishing a due diligence system in terms of pesticide use and residues in food products. However, there is no clear definition or guidance of what constitutes an adequate due diligence system in terms of pesticides and food products. Food businesses have, therefore, approached this in different ways and with different controls and monitoring procedures. The guiding principle, however, has been to establish systems to demonstrate due diligence.

There are some notable industry initiatives that have tried to address these issues and help food businesses meet their statutory obligations. For example, several industry bodies have collaborated to provide general guidance on due diligence (Anon, 1991). On a more practical note, the Fresh Produce Consortium (formerly the Produce, Packaging and Marketing Association) has issued a Code of Practice for Pesticide Control (Anon, 1992). The Code of Practice is an industry standard for produce marketing organisations (PMOs).

The Fresh Produce Consortium's Code of Practice was prepared to guide PMOs on how to develop their own systems of control and procedures for ensuring that the system works. Ultimately, however, even this Code states that PMOs must rely on their own expertise and advises that its recommendations must be carefully interpreted and redefined for each company. The Code of Practice is nonetheless a useful guide for the control and monitoring of pesticide use and residues in produce.

The Code of Practice is in two parts. The first part covers management and procedures and the second part of the Code covers pesticide laboratory guidelines. The procedures and disciplines are intended to assist food businesses to show due diligence on the controls they employ and the scientific methods used to establish results.

Similarly, Campden is producing guidelines relating to a due diligence defence in the context of pesticides in food and drink. These are being produced in consultation with experienced food industry practitioners.

Most food companies have defined their own approach to a due diligence system in terms of pesticides. It is up to each company to interpret the legislation and assess whether they are meeting their obligations in terms of their own products and technical expertise. What is common to them all is that companies have implemented controls and monitoring procedures as part of a quality assurance system in terms of pesticide use and residues in primary products. The former employs some form of check on pesticides used and the manner of use by their suppliers, and the latter requires a degree of residue testing by the company and/or its suppliers.

PESTICIDE RESIDUE SURVEILLANCE PROGRAMMES

As part of the food industry due diligence system, pesticide residues are monitored in surveillance programmes. These involve analysis of residues either using multiresidue analysis for groups of pesticide types or targeted analysis for specific pesticides. The type and frequency of the analysis in specific crops will be determined by some form of risk assessment which takes account of the crop, pesticides applied and source of the produce. For completeness and security it would be desirable to analyse for every conceivable pesticide and for all pesticides applied to a crop in a targeted analysis. However, within a reasonable and fixed budget it is possible to be selective in the frequency and choice of analysis, i.e. undertake a cost benefit analysis.

The range of pesticides which may be used in food production, either in this country or abroad, is very large. Thus any residue surveillance programme, be it by the regulatory authorities or by the food industry, must ensure that the monitoring programmes are targeted to the needs of the organisation. In planning the programme, the available resources must be focused predominantly on those areas where residues are likely to be present. For the food industry this is the aim of the risk assessment. This has to be a product-by-product and company-by-company approach. The aim of the programme must be to satisfy the due diligence system established by the food business.

The statutory surveillance programme undertaken in the UK is based on similar approaches. To some extent the monitoring programme is targeted and is focused on those areas where residues are likely to be present. It is also flexible in that it can make use of new intelligence on the occurrence or toxicity of pesticide residues. The approaches of industry and government surveillance programmes are similar, i.e. they are flexible and targeted, but the priorities are different in terms of the pesticides and crops selected for study.

A typical industry surveillance programme effectively falls into three categories:

1. Continuous monitoring of important products or perceived high risk situations;
2. Rolling programmes covering the main products and sources of supply; and,
3. Monitoring for specific purposes, for example because of an issue relating to a particular pesticide.

The results of individual food businesses' monitoring programmes are not published. These remain confidential to the company and form an essential part of the due diligence system. The results may in themselves be used in the risk assessment and help determine where resources should be concentrated. They may be made available to their customers if they are supplying other food businesses. In general, comments from industry suggest that for the majority of products tested, no residues are detected. Residues exceeding MRLs are found in a small proportion of samples and even these do not exceed the MRL by an amount likely to be a food safety hazard. The general view is that this confirms that food crops are produced according to GAP and any residues remaining on the food product are well within statutory limits. The comment is often made that the food industry is spending a great deal of money in order to produce a large number of results where no residues are detected.

This situation is confirmed by surveillance data generated by the UK Government. The results of their surveillance programme are published annually. This work is undertaken by the Working Party on Pesticide Residues. In 1992 over 3,000 retail samples were analysed by the Working Party for a range of pesticides. In all, results for over 42,000 pesticide/commodity combinations were reported. Overall, no residues were detected in 71% of 3,172 samples. Residues were found in 29% of samples and in 1% of samples MRLs were exceeded. The results were reported to be similar to those in previous annual reports.

It is noteworthy that results of retail samples of UK origin are similar to results of samples that are imported. No residues were detected in 61% of samples of fruit and vegetables, and no residues were detected in 76% of samples of cereals and cereal products. However, in both instances residues exceeded MRLs in only 1% or less of samples.

Data are supplied by industry to the Working Party on a voluntary basis and these results are published by the Working Party (Anon, 1993). This provides the only source of industry surveillance data that is in the public domain. Surveillance by industry is concentrated on commodities, i.e. primary agricultural products and primary processed products such as flour and juice concentrates. In the Working Party's 1992 report, these data included results for over 5,000 samples of a wide range of commodities. In all, over 80,000 pesticide/commodity combinations are reported. No residues were detected in 74% of samples and residues exceeded MRLs in less than 1% of samples. This represented 10 samples out of 5,052. This data must represent only a fraction of the total industry data, but nonetheless it demonstrates that for all food products the majority of the food is free from detectable residues and only a very small percentage contains residues which exceed the MRL.

CONCLUSIONS

The use of pesticides in the production of food crops is necessary in order to ensure consistent supplied of high quality food raw materials suitable for today's markets. Recent food safety legislation in the UK has put greater demands on the food industry regarding its responsibilities towards food safety and quality. It is within the context of this legislation that food businesses have sought to satisfy their responsibilities by controlling and monitoring, in terms of quality assurance procedures, pesticide use and residues by a due diligence approach.

Most due diligence systems include checks on pesticide use and the manner of use, and monitoring of residues in food products. Results from these residue surveillance programmes show that for the major of samples no residues are detected and in only a very small proportion of samples are MRLs exceeded.

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PESTICIDE RESIDUES IN FOOD; COMPLACENCY IS PREMATURE

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ABSTRACT

The existence of unextractable pesticide residues in food and other biological materials is well documented following nearly two decades of study. In a large number of cases they have been shown to be biologically unavailable or, if available, without measurable biological effect. Results from a recently completed international coordinated research programme show that unextractable residues of some compounds used in stored grain are not only biologically available but may affect cholinesterase activity and some serum enzyme levels in experimental animals. Better methods of extraction are needed to avoid uncertainties concerning the biological significance of unextracted residues.

INTRODUCTION

The Food and Agriculture Organization of the United Nations (FAO) and the International Atomic Energy Agency (IAEA) established in 1964 a Joint Division, based in Vienna, to be responsible for research and development in food and agriculture involving nuclear and related biotechnologies. It thus supports the aims of FAO to raise levels of nutrition and living standards by improving the production and distribution of food and agricultural products and those of IAEA which are to foster the contribution of atomic energy to peace, health and prosperity.

One of the ways in which the Joint Division discharges its responsibilities is by organising Co-ordinated Research Programmes (CRPs), an activity which is apparently unique to the IAEA. Each programme addresses a problem of scientific and economic importance related to agriculture or food and typically involves collaboration among 10-20 institutions from different Member States. Those in developing countries are awarded research contracts which provide a modest level of financial support while those in industrialized countries receive research agreements which do not provide funding except that needed to attend research coordination meetings. Topics and objectives for CRPs are normally initiated by staff of the Joint Division although sometimes the initiative comes from an external donor organization. Normally a CRP lasts for 5 years although it is reviewed after 3. Meetings of contract and agreement holders are normally held near the beginning of the programme, after 2-2.5 years and at the end, in order respectively to define the programme to ensure co-ordination, to monitor progress and, finally, to prepare the report. This simple, low key, approach has proved to be a very effective means of technology transfer. One CRP which has been completed recently is of relevance to this session. It was concerned with the biological availability of unextractable residues.

BIOAVAILABILITY AND BIOLOGICAL ACTIVITY OF BOUND RESIDUES IN GRAIN

Background

On the basis of studies with radio-labelled pesticide, it has been known for over 20 years that in most cases, some radioactivity remains in a treated matrix after exhaustive extraction with the solvents routinely used in residue analysis. It was established at a relatively early stage that unextractable residues often represented ^{14}C that had been incorporated into natural products although it was known that some unextractable residues could be released by enzyme treatments. The dearth of evidence of any significant biological activity of unextractable residues, combined with the difficulties of identifying them, limited scientific interest in the subject after the late 1970s.

Nevertheless the Joint Division sponsored a CRP beginning in 1980 to encourage studies of bound residues in soil plants and food. This work (International Atomic Energy Agency 1986) showed that some unextractable residues in soil may become available to plants and microorganisms but the quantities were small (< 3%) and did not apparently produce any response in either group of organisms. There was also evidence that unextractable residues on plants may be available to animals but no observations were made to assess if they elicited any sort of response. Therefore a second programme was begun in 1986 to examine this aspect.

MATERIALS AND METHODS

The programme concentrated on residues in stored grain treated with pesticides after harvest because of the importance of grains in human nutrition and the experimental advantages that relatively small quantities of radioactivity are needed. In addition, the generation of unextractable residues is not affected by climate and the product is palatable to experimental animals.

The grains used included both legumes and cereals. The insecticides included organophosphorus compounds, carbofuran and methyl bromide. Storage periods varied from 6-12 months. Residues were extracted by Soxhlet extraction of ground grain with methanol for 24 hours. Bioavailability to rats of grain containing unextracted residues was assessed in mass balance studies after feeding treated grain for 48 h. Toxicity was evaluated in 3 month feeding trials. Insecticidal activity was measured by bioassay with *Tribolium castaneum* by observations of adult emergence from eggs and larvae incubated in methanol-extracted grain. Experimental details are given in Anon (1992).

RESULTS

The quantities of ^{14}C appearing in urine, expired air and in organs show that the unextractable residues were available to a considerable extent except perhaps for those of malathion in unmilled rice and pirimiphos-methyl in rice. In the other cases between 30 and 86% of the administered radioactivity was found in these fractions. This may underestimate bioavailability to rat as some faecal ^{14}C could derive from biliary excretion. The fact that a part of the faecal ^{14}C could be extracted with methanol (although only 2 participants tried this) gives support to this suggestion.

TABLE 1 Distribution of radioactivity

			% administered ^{14}C			
Country	Grain	Insecticide	Exhaled air	Urine	Organs	Faeces*
YUG	wheat	malathion	17	49	13	2
	"	pirimiphos-Me		82	1	
	"	chlorpyrifos-Me	7	75	4	8
TUR	wheat	malathion	2	62	8	16
	lentil	malathion	2	35	9	45 (26)
	chickpea	malathion	3	29	9	49 (30)
	wheat	pirimiphos-Me	3	29	14	42 (25)
EGY	beans	malathion	8	60	4	3
	"	carbofuran	12	34	25	15
	"	methyl bromide	19	37		24
THA	maize	malathion		30		66
	rice	pirimiphos-Me		14		78
MAL	maize	malathion		36	5	47
	milled rice	malathion		28	4	56
	unmilled rice	malathion		7	6	74
GHA	wheat	pirimiphos-Me	2	33	6	55
PAK	wheat	pirimiphos-Me			30	40
CAN	wheat	pirimiphos-Me		73	1	18 (9)

*Figures in ( ) show % extracted with methanol. Blanks indicate no measurement.

Biological activity

Biological activity is here taken as the ability to cause a measurable change in a biological system. Erythrocyte, plasma and, in some cases, brain cholinesterase levels were measured because of the mode of action of the compounds, and the serum enzymes glutamate pyruvate transaminase (SGPT), glutamate oxaloacetate transaminase (SGOT), alkaline phosphatase (SAP), together with blood urea nitrogen (BUN) were monitored as indicators of hepatotoxicity. Table 2 summarises the results.

TABLE 2 Biological activity

			Residues *	Cholinesterase (% reduction)			Increases in plasma enzymes			
Country	Grain	Compound	mg/kg in diet	RBC	Plasma	Brain	SGPT	SGOT	SAP	BUN
YUG	wheat	malathion	11.3		13-21**		+			
	"	pirimiphos-Me	6.0		36-42**		+		+	
TUR	wheat	malathion	24		29	30				
	lentil	"	6.5		30					+
	wheat	pirimiphos-Me	7.5		38	20		+	+	+
EGY	beans	malathion	1.8	25			+		+	
	"	carbofuran	1.5	40			+	+		+
	"	methyl bromide	30				+	+		+
PHI	maize	malathion	1.5				+	+	+	+
	wheat	pirimiphos-Me	0.5				+	+	+	+
MAL	rice	malathion	0.65	10	20					+
GHA	wheat	pirimiphos-Me	13		36-46**					
PAK	wheat	"	12.5		25	25				

*^{14}C expressed as parent molecule. **whole blood.
Spaces in cholinesterase columns indicate no measurement, in plasma enzymes columns no effect.

The figures show clearly that unextractable residues of all compounds listed could have measurable effects on blood enzyme levels indicating some level of liver damage. Where tested, residues of all but methyl bromide at the concentrations examined reduced cholinesterase levels.

Availability to insects and toxicological effects

It might be anticipated that insects would be at least as sensitive, if not more so, to the effect of unextractable insecticide residues than mammals. The results in Table 3 show that measurable quantities of ^{14}C remained in insect tissues at the end of the feeding period but there are too few data to establish if there is a correlation between these values and any observable toxicological effect or with the unextractable ^{14}C residue content of the grain.

TABLE 3 Insect bioassay of unextractable residue

Substrate	Insecticide application rate	% applied unextracted	^{14}C parent compound equivalent ng/insect	No. of eggs reaching adulthood compared with
Maize	Malathion 10 μg/g	3	0.7	Reduced
Wheat	Malathion 10 μg/g	42	0.5	No effect
Wheat	Pirimiphos-Me5 μg/g	10	-	No effect
	10 μg/g	10	0.01	Reduced
Mungbean	Pirimiphos-Me 10 μg/g	3	0.01	No effect
Wheat	Chlorpirifos-Me 4.5 μg/g	29	0.8	Reduced

The discrepancy between the effects of malathion residues in maize and wheat are quite striking as the fraction left after extraction was over 10 times higher in wheat yet less ^{14}C remained in the insects which were apparently unaffected whereas those fed the maize substrate responded. Presumably the explanation lies in different rates of metabolism in the two substrates.

DISCUSSION

All the insecticides examined left residues in grains that were not removed by 24 h Soxhlet extraction with methanol but which were available to some degree to rats and *T. castaneum*. In several cases these residues produced measurable responses in the test organisms. Of particular concern are the effects on blood cholinesterase levels produced by residues of organophosphorus and carbamate compounds in view of suggestions that these materials may have chronic health effects, for example Rosenstock et al. (1990) including possible immunological effects (Newcombe, 1992; Repetto, 1992), not to mention the speculation of a linkage between chronic organophosphorus intoxication and symptoms resembling of bovine spongiform encephalopathy (Purdey, 1992).

It follows that more effective extraction procedures are necessary in order to avoid the expense of toxicological studies of unextractable residues. This has been recognised in that recently regulatory authorities have required that residues methods should be validated using ^{14}C studies to confirm adequate extraction. The currently most promising approach seems to be supercritical fluid extraction (SFE). This is being actively pursued because of the potential advantages of lower cost in time and materials, selectivity, suitability for automation and reduction in solvent use. In this context, however, the observation of Khan and McDowell (1994) that over 80% of the unextractable residues of some pesticides in soil and plant materials can be released with supercritical carbon dioxide adds to its attractions. However, Khan and McDowell noted that residues of ^{14}C derived from 2,4-D and atrazine were less well extracted, so further work is needed to establish if SFE procedures can be developed to extract all the "biologically active" residues in food products. Whether it is necessary to be able to extract all "biologically available" residues is doubtful since in many cases some of the pesticide derived ^{14}C will have been incorporated into normal chemical components of the system.

Whilst this is the most promising procedure it is not yet time to ignore high temperature distillation (Khan and Hamilton 1980) nor the use of enzyme and hydrolysis pretreatments. It is unlikely that there will be a single procedure suitable for all pesticides and substrates so each situation must be considered individually.

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ACKNOWLEDGEMENTS

The work of the participants of the programme is gratefully acknowledged. They are:

M.T. Akay, Hacettepe University, Turkey
W. Dorough, Mississippi State Univ., USA
B. Dumrugs, Dept. of Agriculture, Thailand
S.U. Khan, Agriculture Canada, Ottawa
W.A. Matthews, ADAS Central Science Laboratory, U.K.
I.Y. Mostafa, Middle Eastern Regional Radioisotope Centre for the Arab Countries, Egypt
N. Neskovic, Institute for Plant Protection, Belgrade
M.J. Qureshi, Nuclear Institute for Agriculture and Biology, Pakistan
V.E. Ramos-Ocampo, National Crop Protection Centre, Philippines
I. Scheunert, Gesellschaft für Strahlen und Umweltforschung, Germany
M.A. Syed, Universiti Pertanian Malaysia
P.O. Yeboah, National Nuclear Research Institute, Ghana

TECNAZENE - A CASE STUDY OF CONTENTMENT OR CONCERN

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ABSTRACT

The post harvest treatment of staple crops has a high profile with regulators and consumer groups alike. Potential risks to health and margins of safety have to be set against benefits which are often obscured in the debate. Tecnazene has been used as a post-harvest treatment on potatoes to control sprouting for forty years. Monitoring over the past ten years has highlighted the difference between worst case theoretical calculations and surveillance or intake studies.

INTRODUCTION

Within the potato industry, storage for some growers is becoming a highly sophisticated capital intensive business with the continued move to larger scale units. There is also a strong desire by some retailers to reduce the reliance on all post harvest chemical treatments. Both these trends are of course market driven - the first by demand from processors and pre-packers for quality and reliability of supply, the second by the public perception that chemical treatments are inherently undesirable. It is not surprising that post-harvest treatments, whether in potatoes, cereals or fruit, should come under close scrutiny. After all, such applications are closer to the point of consumption than treatments in the field; they are also applied directly to the edible part of the crop. Both these factors play a part in influencing the level of detectable residues. Post harvest treatments are therefore a prime target for the debate - 'contentment or concern'. This paper seeks to examine the issue using data specific to tecnazene.

To set the scene, tecnazene was first introduced as a fungicide in 1940 (Duncan 1979), but it was soon identified by Brown (1947) as having potential for use as a sprout suppressant in potatoes. Subsequently it was introduced as a commercial treatment in the 1950s. Today it is usually formulated alone either as a granule or dust, but it is also sold in mixture with thiabendazole or carbendazim. In 1990 over 700,000 of the 3.5m tonnes of potatoes stored in the UK were treated with tecnazene. For over 40 years it has provided growers with a cheap and effective method of protecting potatoes applied as the store is loaded.

THE PERCEPTION OF RISK

If post harvest treatments are to protect crops during storage, of necessity they will contain detectable residues - in order to work. It is therefore unreasonable to expect them to disappear completely between storage and consumption. Processing and preparation significantly reduce residues, but the key question is by how much - and whether what truly remains is of any toxicological significance. Consumers still misunderstand perceived and actual risk. Maunder (1990) concluded that "Residues should be treated with respect, but they should also not cause people to leave their brains behind whenever the word is mentioned". Surveys in various countries show that consumers perceive that the presence of pesticide residues is the main, if not the only, health threat associated with food. Most scientists agree that pesticides do not present the greatest health risk but rather the least (Ames, 1990; Brackett, 1991; Saunders, 1991). The greatest risks are actually those least recognised by consumers and, until recently, even by experts in some governments. In reality nutritional imbalance, followed by harmful micro-organisms, bacteria and mould, should be our main concern. Post harvest treatments like tecnazene in fact reduce our exposure to a range of natural toxins which can be found in stored produce.

BALANCING THE BENEFIT

Before assessing whether the risks from pesticide residues in our diet are significant, it is essential to consider what benefits they bring to growers, processors, retailers, and the consumer. In the case of tecnazene we have already identified a reduction in risk for the consumer from good sprouting and disease control. Use of tecnazene also ensures a reliable supply of high quality potatoes. Growers do not require sophisticated systems for application or storage and can supply all sectors of the market. In contrast, potatoes from refrigerated storage, where no chemical treatment is used, can only deliver to the unprocessed market. Growers carry a significant risk in capital expenditure, running costs and potential losses in quality from diseases, increased sugar content, softening, dehydration and chilling (Cunnington, 1994).

However, despite a range of risks with refrigerated storage, its development has come about primarily as a result of the demand for residue free potatoes in the pre-packed market. The question is, "are consumers getting the best quality potatoes from such storage"? Many in the industry think not and believe that retail, not consumer pressure has been the driving force initiated by the media's concern about products like tecnazene.

Pooley (1993) believes that policies regarding tecnazene on the part of some retailers do not genuinely reflect consumer concerns. "Residues have become part of the competitive scenario between retailers. Some of the genuine anxieties of consumers have been triggered by mis-information in the media, in particular the lack of understanding of the need to evaluate all potential hazards in potatoes not just the risks which may or may not be added by modern farming methods".

EXPOSURE TO TECNAZENE IN THE UK DIET

When assessing risk to consumers from residues of a new agrochemical in food, regulators draw their conclusions from an extensive database. However, this may be restricted in its scope, and certain assumptions are made which effectively build-in very wide margins of safety. When a compound has been in use for several years, it becomes possible to draw upon a much wider data source, including surveys of the raw, cooked and processed foods which people actually eat. These surveys show that the wide margins of safety, which are necessary before a product is given approval, are borne out in practice. Indeed, in the majority of cases, actual intakes are only a fraction of the levels which were considered to be safe at the time of approval.

There are different ways of estimating dietary intakes of pesticides in food, with each presenting a more refined and realistic estimation of intakes. These methods were reviewed by Hignett (1991). Those upon which most new approvals are based are derived from the maximum residue level (MRL). The MRL is the maximum residue level which is likely to occur when the pesticide is used according to the label, ie. according to good agricultural practice. MRLs are normally set from data from controlled residue trials and effectively represent the level of the residue found at the farm gate. It should be stressed that MRLs are not safety limits.

The simplest estimate of dietary intake in food is the Theoretical Maximum Daily Intake (TMDI). The TMDI is normally the parameter which is used to judge the risk to consumers from a new compound. It is the product of the MRL in mg/kg, multiplied by the 97.5th percentile of daily food consumption for the relevant commodity. In calculating a TMDI, certain assumptions have to be made, but clearly they do lead to gross over-estimates of the real residue picture:

(i) the consumption of each individual commodity is considered to be in the top end of the normal range (97.5th percentile);
(ii) all of the particular commodity eaten has been treated and contains residues at the proposed MRL;
(iii) there is no loss of residue during transport, storage, processing or preparation of foods prior to consumption.

At the next level is the Estimated Maximum Daily Intake (EMDI). This is rather more refined than the TMDI as it takes account of the distribution of residues between edible and inedible portions of the food, and also the effects of storage, processing or cooking on residue levels. The most sophisticated method for estimating intake is the Estimated Daily Intake (EDI). This calculation includes the proportion of the crop that is actually treated, and also the ratio of home-grown to imported produce which is consumed. Alternatively, the EDI uses actual residue levels gained from surveillance data.

The EMDI can be calculated, even for new chemicals, where data are available on residues in the edible portion of the crop, and residues which are left following processing or cooking. The EDI can only be calculated when a product has been in use for some time, as is the case with tecnazene. The UK's extensive rolling programme on pesticide residue surveillance is an excellent 'watch dog' in monitoring and providing real life data for these calculations.

Fig. 1 Tecnazene residues in potatoes: annual surveillance data (source WPPR Annual Reports)

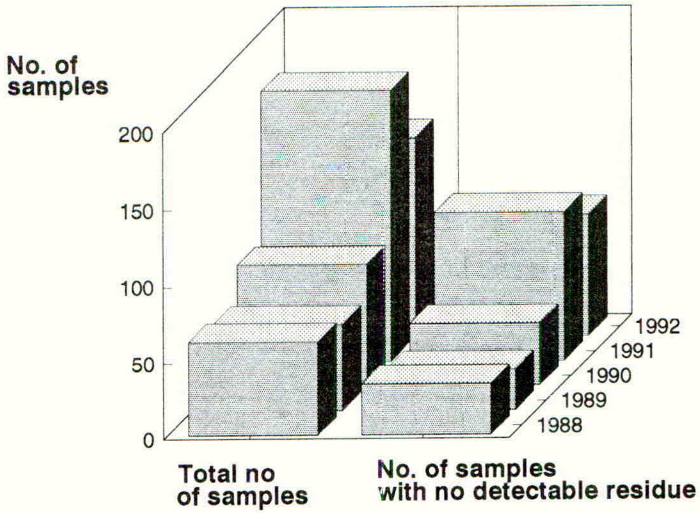
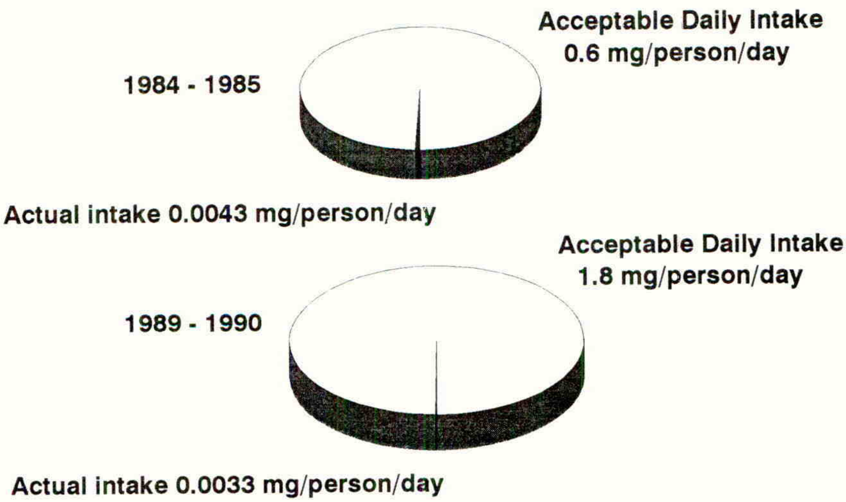


Fig. 2 Actual intakes of tecnazene (mg/person/day) compared with ADI (Source: WPPR Total Diet Studies)



For tecnazene, it is possible to calculate the TMDI using the current UK advisory MRL of 5 mg/kg and the 97.5th percentile consumption of potatoes in kg/day (0.316 kg). Therefore, assuming a consumer of 60 kg, the TMDI is:

$$\frac{5.0 \times 0.316}{60} = 0.0263 \text{ mg/kg body weight (bw)/day}$$

This figure represents 88% of the current advisory Acceptable Daily Intake (ADI) of 0 - 0.03 mg/kg bw/day. If it was a new compound this might start giving rise to 'concern'. However, reality is a long way from theory. Examination from surveys of UK produced main-crop potatoes, carried out by the Working Party on Pesticide Residues (WPPR) (HMSO 1990, 1991, 1992a, 1993), shows that in each year, at least half of the samples tested had no detectable residues of tecnazene (Figure 1). Furthermore, the percentages of samples below the current UK MRL of 5 mg/kg in each reporting year were as follows: 1988, 97%; 1989, 100%; 1990, 100%; 1991, 99% and 1992, 100%.

Therefore, actual levels of consumption are far lower than those calculated by the TMDI approach. This is confirmed by data from Total Diet Studies (TDSs), conducted in the UK by the WPPR (HMSO 1992). TDSs are undertaken to determine average intakes of dietary constituents, and are analysed every 5 years for the presence of pesticide residues. Total Diets have been analysed twice in the last ten years, in 1984-85 (HMSO 1989) and in 1989-90 (HMSO 1992b). Data from these surveys are represented schematically in Figure 2. In 1984-85, the ADI for tecnazene was set at 0.01 mg/kg bw/day. A 60kg adult could therefore safely consume 0.6mg tecnazene per day. The TDS showed that average actual consumption of tecnazene was 0.0043mg per day, or just 0.72% of the ADI for an adult. The availability of more modern toxicological data in 1989-90 allowed the ADI to be increased to 0.03mg/kg bw/day, reflecting the higher No Effect Levels (NOEL) demonstrated by the new data. This meant that the total amount that a 60kg adult could consume was 1.8mg per day. The TDS revealed that the amount actually being consumed had gone down slightly to 0.0033mg per day. This represents 0.18% of the adult ADI.

To conclude, this view by Conning (1989) is most apt - "if you eat a hefty 320gms helping of treated potatoes four times a day, you would be within the ADI of the compound. The over eating would get you before the tecnazene did".

THE FUTURE FOR POST HARVEST TREATMENTS

In any discussion about the future use of post harvest treatments like tecnazene the first criteria is that they should meet modern regulatory requirements. The second is that if approved, retailers should not try to gain a competitive position in the market place by refusing to accept the product, thus implying that it is unsafe. The rejection of an approved product has a 'bow-wave' effect through the whole industry leaving uncertain messages in its wake, which contradicts the approvals process. As technology develops, changes in storage management will be implemented. Many initiatives are currently being developed by retailers alone or in cooperating groups along with organisations like the National Farmers Union (NFU).

In the foreseeable future, perhaps until a new generation of storage aids are developed, it seems likely that an approach which balances environmental and chemical methods is the best way forward. Just in the same way as integrated crop management (ICM) is being promoted for growing the crop, a concept of integrated store management (ISM) is both practical and likely to be more acceptable to the public. In accepting the objective of minimal chemical use, we should also be realistic about over reliance on any one chemical, acknowledging that a mixed programme will lead to minimum residues and a better environmental approach. To make this happen all sectors of the industry must act on these core principles.

Nonetheless the farming industry should be under no illusions about the long term availability of post harvest treatments. Hignett (1992) reported that "Government policy, consumer demand and international pressure have created a climate where post harvest chemical treatments will find it hard to survive." Hignett identified three elements which put pressure on the continued use of such treatments. Firstly, harmonisation and the demand by many EC governments towards lowering MRLs - often for political reasons. Secondly, requirement from Directive 91/414/EEC for additional data - which may not be economically justifiable. Lastly, as discussed, the continued perception of risk by consumers with no allowance for any benefits.

Looking specifically at the future of potato storage in the UK, it is clear that the point has not been reached at which the industry can wholly dispense with post harvest treatments. Currently the bulk of the UK crop is supplied from ambient storage which relies on the judicious use of chemical treatments. Many advisors believe this is the best system for storing potatoes. Statham (1990) states "It is my personal view that the industry should hang on to storage chemicals for as long as possible, because I do not believe refrigeration will necessarily provide the complete answer to potato storage difficulties for most producers". For tecnazene, Cunnington (1994) reports that "UK growers value it highly" and that an industry wide survey indicated that the implications, should such post harvest products be withdrawn, would be considerable.

If these chemicals were not available, the potato industry must realise where this leads. Potato production will continue to move further into the hands of those larger producers with refrigerated storage supplying a proportion of the fresh market. Significantly, more fresh or processed product would have to be sourced from outside the UK. This story could be repeated in other market sectors relying on produce treated with post harvest chemicals.

CONCLUSIONS: PESTICIDE RESIDUES IN FOOD - CONTENTMENT OR CONCERN

In this paper we have addressed the real risk of a specific post-harvest treatment for potatoes, in the context of both alternative, non-chemical storage techniques, and the long-term viability of the UK potato industry. Pivotal in this is the question surrounding pesticide residues in food: contentment or concern. Our conclusion is that post harvest chemical treatments still play a key role in modern agriculture.

Regulatory processes ensure a product is only approved when an adequate margin of safety exists. However, those calculations are based on extremely conservative assumptions for products such as tecnazene. With the benefit of food surveillance and dietary survey programmes, a realistic view of the levels of residues in food can be determined - food as consumed rather than produce at the farm gate. In the case of tecnazene, it can be shown that the actual levels of consumption are very, very low, and nowhere near the maximum level which could safely be consumed.

The reality, rather than the perception is that even with the post harvest treatment of a staple crop, undeniably a worst case, residue levels are of no concern. So should we be content? The answer is that whilst having no concern, there is also no room for complacency. In reaching the view of 'no concern', data on actual levels of residues in food are critical. Regulatory, industry and consumer contentment is only deserved by regularly referring to continued surveillance programmes and the responsible use of a balanced programme of storage techniques including the use of post harvest treatments.

ACKNOWLEDGEMENTS

The authors would like to thank members of the Tecnazene Task Force (TTF) for support in the production of this paper.

The TTF was formed in 1989 in response to the initiation of the UK review of tecnazene. It comprises, two approval holders, Zeneca Ltd, Hickson & Welch Ltd and five other licensee companies - Agrichem Ltd, Atlas Interlates, Avon Packers, Dean Agrochemicals and MSD AGVET.

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Session 3B

Integrated Pest and Disease Management - Theory and Practice

Chairman	Professor H van Emden
Session Organiser	Dr D R Dent
Papers	3B-1 to 3B-4

STRATEGIC MANAGEMENT IN THE DEVELOPMENT OF INTEGRATED PEST AND DISEASE MANAGEMENT PROGRAMMES

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ABSTRACT.

Scientists and business managers often use strategic thinking in a superficial way. A strategic approach to IPM acts to co-ordinate and facilitate the actions of multidisciplines to understand and achieve the overall goal of the programme. Strategic implementation should be flexible to adapt to changing environmental factors which range from the immediate crop regimes to socio-economic factors. Used as a philosophy rather than a set of instructions strategic management adds value to an IPM programme by giving it focus and direction.

INTRODUCTION.

Strategic management provides a method of integrating pest and disease management programmes in a changing environment. A strategic approach to IPM acts to co-ordinate and facilitate the actions of multidisciplines to understand and achieve the overall goal of the programme. The strategic implementation should be flexible to adapt to changing environmental factors which range from the immediate crop regimes to socio-economic factors. Therefore, the programme should be monitored and a method of programme control or assessment should be established. However, conflicting interpretations of 'strategic management' often result in programmes that fail to fulfil the initial expectations of those supporting the work. IPM programme failures can occur because of a failure to understand and agree long term goals, failure to recognise barriers to implementation, failure to implement the strategy, or because of a failure to modify aspects of the strategy in a changing environment. IPM opportunities can be missed because of a lack of understanding of strategic management.

Conflicts often occur during the development of a strategy either in the business or scientific environment through contradictory definitions of 'strategic management'. Organisations frequently acknowledge the necessity of 'strategic thinking' but use the concept more as a 'comfort action' rather than a considered implementation of co-ordinated actions, in a changing environment, designed to achieve a long term goal.

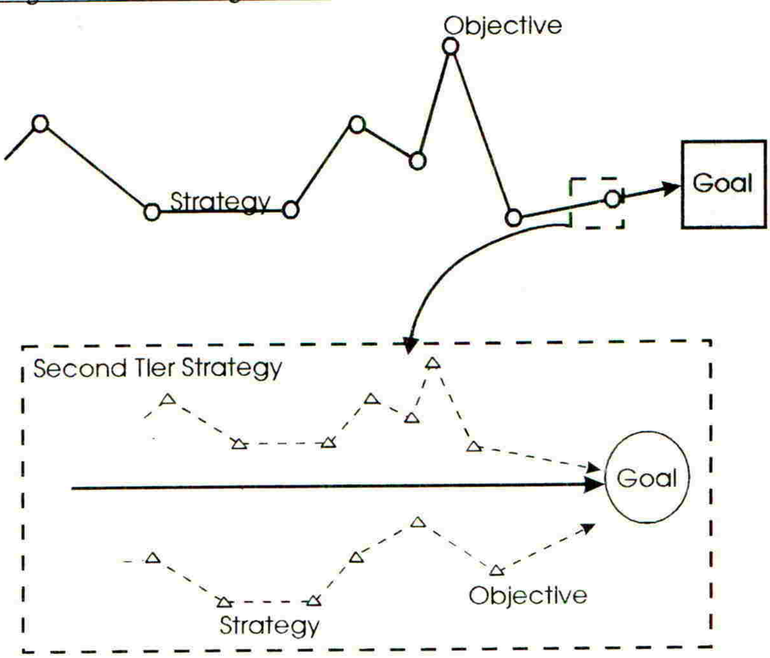
This paper is designed to challenge the generally superficial approach of some scientific and business managers to aspects of strategic management. It will develop specific points of strategic thinking and demonstrate why potentially successful IPM programmes can fail.

WHAT IS STRATEGIC MANAGEMENT?

Workers often mix and match strategic jargon without realising the contradictory nature of their language. Strategy, goals and objectives are frequently applied to the same concept. Therefore, strategic management must be defined and understood by those involved with the IPM programme. Within a multinational / multidiscipline group the use of metaphors to establish an understanding of the concept of strategic management can be valuable. For example, a journey is a metaphor commonly used to discuss the concept of strategic management. Before setting out on a journey one must have a defined destination, the goal, consideration must be given to the route to be taken in relation to the terrain, the strategy in relation to the environment and the progression along the route can be measured using 'mile stones', the objectives (defined and measurable points of the strategy).

For groups within the IPM system the overall goal and agreed strategy should be understood. However, second and third tier goals and strategies will be required. A first tier objective may act as a second tier goal for a sub group working within the programme. A second tier goal would also require a second tier strategy to achieve it. Again the second tier strategy should be monitored in relation to a changing environment.

Fig. 1. Diagram to show strategic levels.



Strategic management adds value to an IPM programme. Development of a strategy designed to achieve a long term goal gives focus and direction to a programme. The strategy chosen provides a method of prioritizing objectives, generating a system where objectives may be achieved in parallel, speeding up the programme development. It also helps to avoid programme pitfalls such as addressing every issue at the same time, 'the blunderbuss approach' or only acting on familiar or easier objectives. The strategy chosen should be flexible in response to the changing environment. Again a metaphor such as a migrating flock of birds is a useful way of describing the concept. In this example an IPM programme can be represented by the flock and the multi disciplines by the individual bird. As the flock progresses along its route the birds change position in the flock according to dominance, energy and weather conditions which might demand subtle or extreme changes in direction. Likewise as the programme progresses the objectives may change according to the changing competitive environment. Consideration and regular monitoring of the environment and of the objectives of a strategy allow modifications to be made. The chosen strategy is not a law but a technique that is as successful as the skill of those applying it. Strategic management should therefore be viewed as a philosophy of working style rather than a set of instructions guaranteeing a finished product.

It is apparent that sub groups working within a programme need more than a notional communication system for co-ordination. The tensions, within and between groups, created by a changing environment and the resulting modified strategy should also be recognised. In a dynamic environment, change becomes more complex and the decision making process more difficult. Therefore, the participant expectations should be realistic. A conciliatory approach between groups may be more constructive where no 'correct' answers are available.

Strategic management should be divided into three main sections, that of strategic analysis, strategic choice and strategic implementation.

STRATEGIC ANALYSIS.

Strategic analysis assesses the key influences on the present and future well-being of the IPM programme and on the choice of strategy available. Key influences include the environment, resources available and stakeholder expectation. The key environmental influences can be summarized using a STEP (Political/legal, Economic, Socio-cultural and Technological) analysis. A brief STEP analysis for the development of entomopathogenic nematode products in Europe has been summarized below. Entomopathogenic nematodes have been developed as bioinsecticides applied against soil dwelling insect larvae.

<u>An example of a STEP analysis.</u>

Environmental factors that could affect the successful introduction of entomopathogenic nematode products into European countries include;

<u>Political/Legal Factors.</u>

- increasing soil insecticide restrictions.
- government subsidized crops.
- registration of biological control agents in specific countries or crops.
- legislation requiring food or crop standards where no control alternative is appropriate.

Economic Factors.

- Recession environment reducing ability to finance pest control.
- Exchange rate fluctuations.
- Labour market expensive.
- W. European crops are significantly threatened by Eastern European markets.

Socio-cultural Factors.

- Environmentally friendly products are more acceptable.
- Niche customers will pay for a environmentally friendly premium.
- Increasing interest in the environment.

Technological Factors.

- Large scale production of entomopathogenic nematodes is possible.
- Entomopathogenic nematodes can be formulated to provide products with a prolonged shelf-life at room temperature.

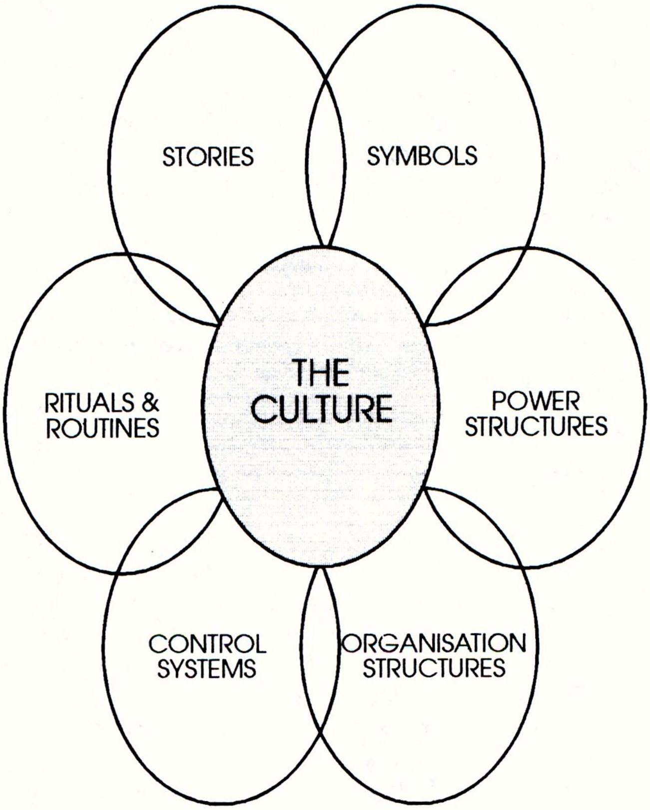
Project resources, the second key influence, tend to be budgeted in advance. The perceived market for the product should justify the cost of formulation research, of generating field data, manufacturing and distribution systems and give a return on the investment. Strategic thinking provides focus to a project requiring prioritization of objectives. Proactive behaviour should result in the effective use of resources as better co-operation between groups results in the efficient utilization of sites, people, experience and information.

The final environmental factor is described as the stakeholder expectation. Stakeholders include employees, managers, shareholders, suppliers, customers and communities. In IPM programmes first tier stakeholders often include specialist scientists and commercial companies, while second tier stakeholders could include distributors or growers. Stakeholder expectations are built on past experiences, assumptions and beliefs and will reflect specific organisation cultures. Expectations are likely to differ as the past experiences, assumptions and beliefs creating each organisation culture are different. Where IPM programmes are created by different organisations working together, differing expectations of the programme can cause conflict between groups. The diagram in Fig.2 can be used to demonstrate the extremes of conflict that can arise between a scientific and commercial group working together. Here, two extreme examples of a scientific and commercial culture are contrasted by loosely dividing the culture into areas of 'stories', 'symbols', 'power structures', 'organisational structure', 'control systems' and 'rituals and routines'.

Stories.

Scientific reputations of theoretical biology incorporating complex mathematical concepts can be intimidating, while stories of grants won or prestigious papers given may be irrelevant to a commercial product development manager. Speedy introduction of a product or expensive dinner parties may appear risky or frivolous to an academic worker. Stories of poorly paid scientists working for the morally higher goal of job satisfaction, dedication to the job and commitment to a field that will benefit the environment contrasts with the 'high salaries' of commercial business managers who's main goal is to make a profit. Both statements are unfair but this is the reality that builds the culture. Myths and stories are not necessarily based on fact but can still show a significant impact on the culture and reactions to different cultures.

Fig.2. The culture of an organisation.



Symbols.

The white coat of the scientist and the chic suit of the business manager are classic symbols conveying different extreme images. The respective uniforms provide direction as to specific roles but also serve to separate the different cultures.

Power Structures.

Commercial managers may be seen to wield more power through the control of financial resources contributed to a programme. However, scientists may exert control as the holders of specialist knowledge or as the unofficial leaders through academic reputation and experience.

Organisation structures.

Scientific projects may be hierarchical where a senior scientist gains funding of a project and leaves the day to day detail to a junior. This can speed up decision making. In larger commercial organisations decision making may be delayed while being processed through multiple layers of bureaucracy. In smaller commercial companies projects may be co-ordinated by relatively young personalities who expect an equal opportunity to place an argument as a senior scientist.

Control Systems.

In the commercial environment work is standardized by Standard Operating Procedures (SOP's). However, in a rapidly changing environment competitive pressure often places a strain on the ability of workers to follow SOP's. Work may be equally controlled in the scientific environment by accepted experimental practise. The design of a robust experiment relies on the experience and skill of the scientist. Both groups use financial monitors as a means of control. However, budgetary control cannot be used as an indication of a successful strategy. Sales or profit do not measure strategy unless as part of agreed objectives within the strategy.

Rituals and Routines.

Scientists are more likely to be comfortable following a logical set of steps in a project, only moving on when satisfied that all questions have been answered. Scientists may feel happier taking the time to consider options and be sure before proceeding. A commercial manager may prefer to facilitate change by establishing parallel projects assuming that each project will achieve their goals to finally combine to a finished product. Informed risk taking achieves goals and therefore rewards faster.

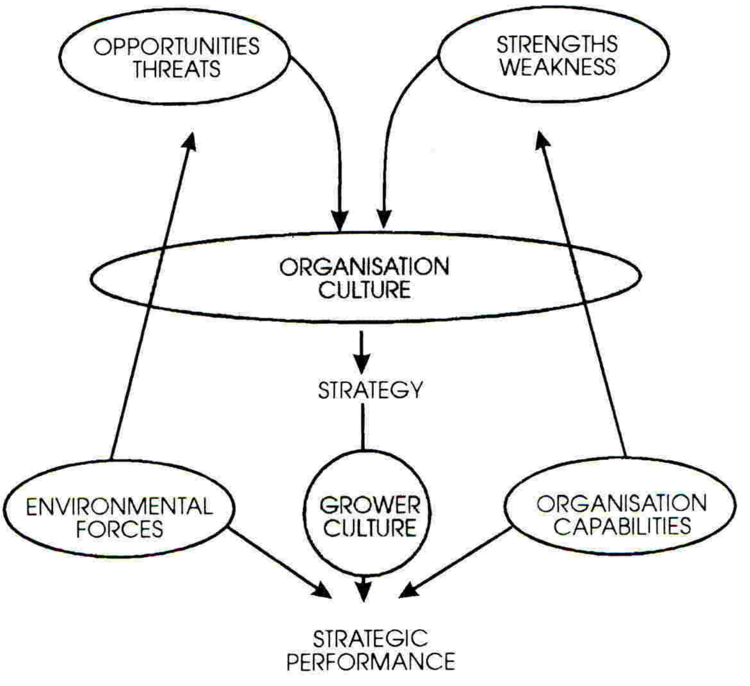
The generalized examples above have been designed to show the extreme contrasts that may occur in groups working to establish IPM. When confronted by an extremely different culture it is far easier to make an obvious judgement rather than acknowledge that in each culture the respective actions or priorities are appropriate. Recognition of the value of a different culture rather than criticising it is obviously more constructive but difficult to achieve. The fact that someone wants to be different is often perceived as a critical gesture rather than a decision based on different experiences.

The role of the culture in strategic management is described in Fig 3. Here the example of an introduction of a new formulation for entomopathogenic nematode species in the Steinernematidae family has been used to demonstrate strategic thinking and the role of the organisation culture in the success of a product introduction.

An opportunity has arisen through the development of a new 'Water Dispersible Granule' (WDG) formulation for Steinernematid entomopathogenic nematode products. This opportunity enhances the current strengths of existing products. Product strengths may be described as follows. Steinernematid entomopathogenic nematodes can be fermented on a large scale (80,000 litre fermentors at a concentration of 150,000 nematodes /ml), formulated into products that have a extended unrefrigerated shelf-life and sprayed using conventional spraying equipment. Entomopathogenic nematodes actively seek out and infect soil dwelling insect hosts providing a significant advantage over entomopathogenic fungi and insecticide products. Also, entomopathogenic nematodes do not have to be registered in most European countries. This is because entomopathogenic nematodes cannot survive at mammalian body temperatures, protective clothing does not have to be worn during application, and because entomopathogenic nematodes have no significant impact on populations of non-target organisim. This can accelerate product introduction to under two years compared to the five to seven year registration process for chemical insecticides. The WDG formulation provides further strengths to the commercial development of the product. The formulation has a shelf-life of at least four months at room temperature and can be stored longer if refrigerated. This allows flexibility in customer forecasting and in distribution systems. The new formulation consists of a water dispersible granule. Semi-desiccated nematodes are concentrated in each WDG granule. The concentration of nematodes can be weighed out to treat the required crop areas. As each container can be opened and resealed the area to be treated can vary. Following feedback from distributors the packaging has been reduced making a 'green' product more green.

Product weaknesses are not associated with the formulation but with the nematode species. That is, the nematode species can be limited by cold temperatures and must be applied to moist soil because entomopathogenic nematodes are susceptible to sudden desiccation and ultra-violet light. However, these weaknesses are common to all competitive entomopathogenic nematode products currently available. One possible threat from the new formulation is that the momentum of product sales from the established formulation may be diminished because the new formulation may not be associated with the old formulation. A further threat may be posed by soil insecticides. However, use of entomopathogenic nematodes ensures that no phytotoxic effects occur, protective clothing does not have to be worn, and soil dwelling insect pests in niches inaccessible to chemicals can be effectively controlled.

Fig.3. The role of a organisation culture in strategic management.



The STEP analysis above demonstrates some of the factors that provide a favourable environment for the introduction of a bioinsecticide such as Steinernematid entomopathogenic nematode species in a WDG formulation. Organisational capabilities can be enhanced through corporate marketing partners. This widens market opportunities and links a relatively 'new' product type to an established corporate name. Large scale production formulation facilities ensure product supply and in-house expert research, formulation and field development capabilities ensure product support is available to corporate partners.

A general SWOT (Strength/ Weakness/ Opportunity/ Threat) analysis, of the organisational capabilities and the environmental forces should help ensure a positive reception of the new WDG Steinernematid formulation. The company culture will also have an impact on the successful introduction of the product. In this example, the product is to be launched by a UK based wholly owned subsidiary of an American company. The product launch benefits from a combination of pragmatic and entrepreneurial UK managers combined with the optimistic and dynamic American parent. Here the international mix of cultures combines to synergistically speedily develop a product with a commitment to biorational products.

Having examined the strategic analysis a strategic choice must be made. This is often made in conjunction with corporate partners. The commercial strategy to introduce the product could therefore be defined as the first tier strategy and will be based on the product cost, availability and price of alternative products, possible government financial support for growers, any 'green' premium available, and the investment required to raise the profile of the product in the market. A second tier strategy would be required to support the commercial development of the product. For example, in preparation for the product launch the following objectives would have to be achieved;

- confirm efficacy of product is equal to current formulations.
- ensure formulation is compatible with standard spray equipment.
- ensure any registration requirements are fulfilled.
- confirm shelf life of the product is competitive with current formulations.
- supply distributors with a breakdown of the competitive advantage of the WDG formulation.

For example, at the second tier level a secondary strategy would be required to achieve the goal of ensuring that the efficacy of nematode species formulated in WDG are equally effective at controlling the insect pest as the same nematode species in the current formulations. This may be achieved by three different approaches. The new formulaiton could be compared with chemical standards and current formulations applied against a specific pest. The efficacy of the new formulaiton could be assessed with a chemical standard against a specific insect pest. Trial data of WDG products against different insect pests could be presented to demonstrate efficacy. These approaches in parallel would provide sufficient data to convince a distributor of the value of the new formlation compared to those currently available. This avoids the necessity of providing data through a compelete pest development cycle. In reality, as the new formulaiton simply acts as a carrier for the nematode, it is not necessary to demonstrate that the nematode can control the pest under a variety of conditions. This has already been achieved with the current formulation. However, it is necessary to establish that as the carrier the formulation has no effect on the viability of the nematode species.

When designing the strategy it is also important to consider a further stakeholder expectation. The grower expectations can be used to demonstrate the impact of stakeholder expectations on the successful implementation of a strategy in the European market. The grower expectations are also built on past experiences, assumptions and beliefs and will reflect organisation culture. This can also be divided into areas of 'stories', 'symbols', 'power structures', 'organisational structure', 'control systems' and 'rituals and routines' as in Fig. 2.

Stories.

The grower may not have experience of using entomopathogenic nematodes to control insect pests. He may be expressing an interest because his alternatives are limited. However, he may have heard stories about biological control that make him cautious about investing in new methods. If he has a strong background in chemical use he may be sceptical about efficacy or believe it is a fashion, or that it is bound to be more expensive than chemicals.

Symbols.

The grower may see himself as old fashioned and prefer the old ways. Sophisticated use of biological agents may not suit his image of himself. However, a grower investing in new glasshouses and temperature regulating equipment may embrace new technologies to protect his crop. Plastic product packaging may not suit the grower image.

Power Structures.

Senior management may view biologicals as a niche product and of minor interest. A junior manager however,may be highly committed to IPM and need support to minimize any perceived risk by moving to something new and to gain the approval of senior management.

Organisation structures.

Organisation structures in the growing system may limit the use of entomopathogenic nematodes. Organisation structures are linked to power structures. The rigidity of an organisation may limit the development of the concept of insect control using entomopathogenic nematodes.

Control Systems.

Information systems may not provide information necessary to anticipate pest problems. Product orders may be placed at the last moment, to save money, and may not allow sufficient time for the nematodes to control the pest before significant damage has been caused.

Rituals and Routines.

The grower may not be able to adapt his system to accommodate the use of nematodes 'this is the way we have always done it'. The grower may not understand the importance of anticipating pest damage and may assume that orders can be placed in the same way that chemicals are purchased.

The role of the grower culture is often discounted, but the simple commitment or scepticism of a grower or a distributor can significantly affect the impact of the introduction of a product.

The performance of the strategy should be monitored during implementation. This requires a regular assessment of the second tier objectives and strategies and periodic assessments of the first tier objectives and strategies. Strategic assessments should go beyond financial control to more subjective performance indicators such as competitive standing or market penetration.

Finally, individuals in an organisation achieve goals and make a strategy function. With good communication providing relevant information the conflicts caused by strategic changes can be reduced. This can produce effective contributions to strategic development and a successful implementation of the chosen strategy.

Acknowledgement.

This paper has been developed from concepts in 'Exploring Corporate Strategy' G. Johnson & K. Scholes.

THE TALISMAN EXPERIMENT - OBSERVATIONS AND IMPLICATIONS FOR INTEGRATED PEST AND DISEASE MANAGEMENT OF ARABLE CROPS IN THE UK

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ABSTRACT

TALISMAN (Towards A Lower Input System Minimising Agrochemicals and Nitrogen) is a long-term multi-disciplinary experiment to measure the economic and agronomic consequences of adopting low-input arable cropping systems. The experiment is designed to allow the component effects of reducing or omitting nitrogen fertiliser, herbicide, fungicide and insecticide inputs to be studied over contrasting Standard and Alternative six-year arable rotations. Two contrasting management regimes are compared: Current Commercial Practice (CCP) in which full rates of nitrogen and pesticides are applied, and a Low Input Approach (LIA) in which nitrogen is used at half rate and pesticides are omitted or applied up to a maximum of 50% of that used in CCP. Results so far indicate that profitable reductions in use of nitrogen and pesticides are possible but omitting or reducing certain inputs has on occasions resulted in economic losses, demonstrating the need for increased precision in the application of low-input systems. TALISMAN shares with Integrated Pest Management (IPM) the objective of achieving economically sustainable reductions in pesticide use. Gathering diverse data in large-scale, whole-system, studies such as TALISMAN is important in bridging the gap between research and the implementation of IPM. Findings relevant to IPM in the first three years of work are presented and their implications for IPM discussed.

INTRODUCTION

The economic findings of the Boxworth Project (Greig-Smith *et al.* 1992) demonstrated that the rational use of pesticides in a cereal rotation, as exemplified by the "supervised" pesticide regime, compared favourably with the "full insurance" regime based on the prophylactic use of pesticides. The supervised approach to crop protection, relying on crop monitoring and treatment thresholds to trigger the use of pesticides, was shown to be both economically viable and environmentally desirable. However, the Project was unable, because of the design, to analyse the components of yield effects and was restricted to cereals and oilseed rape at one specific location.

The design of TALISMAN addresses many of the compromises found in the Boxworth Project: namely, the addition of treatment factors including crop rotation, fertiliser use, modification of input levels to reflect changing farm practice, geographic diversity and experimental replication. TALISMAN thus evolved in the wake of the Boxworth Project as a long-term multi-disciplinary study to focus primarily on the economic and agronomic implications of adopting low-input arable farming systems at four diverse locations in England (Cooper, 1990).

Relationship with IPM

Integrated pest management (IPM) is generally accepted as a control strategy that incorporates chemical, cultural and/or biological control measures. Within IPM there is a common purpose of becoming less reliant on pesticides, minimising their use and environmental impact. The aim of an IPM strategy is stable and sustainable long-term pest control. Vereijken *et al.* (1986) reviewed the reasons for the relative lack of success of arable crop IPM and proposed that IPM should be considered within a wider concept of integrated crop production or an Integrated Farming System.

TALISMAN was not conceived or designed with an IPM remit. The experiment lacks many of the cultural and biological elements of pest control required in an IPM system. However, TALISMAN shares with IPM the common objective of achieving economically sustainable reductions in pesticide use. According to the classification of pest management defined by Tait (1987) both the CCP and LIA regimes under test in TALISMAN are in the "Rational Reductionist" pest management group which requires that each pesticide application be justified on scientific, technical and/or economic grounds. Indeed, a large proportion of crop protection practitioners in the UK would probably claim to fall within this definition of optimised/selective pesticide use since the general move away from prophylactic or routine pesticide use of fifteen or more years ago.

Nevertheless, TALISMAN incorporates many features of the IPM concept: pesticide use is minimised by reduced dose applications and avoidance of routine use. Monitoring, and to a lesser extent, forecasting of pest, disease and weed problems are utilised together with use of treatment thresholds where possible. Biological and "novel" methods of non-pesticidal control are not included. However, the effect of pesticides on beneficial and non-target invertebrate species is being monitored, but will not be considered in further detail here. Although cultural control is not of high priority in TALISMAN, the main advantage of the design in relation to IPM is the long-term study of six-year rotations with contrasting high- and low-input requirements. Observing cumulative rotational effects, such as those associated with disease and weed control and the overall response of the rotations to low inputs, should provide useful indications for the development of IPM systems.

DESIGN AND TREATMENTS

TALISMAN started in 1990 and will end in 1996 after six cropping years. The experiment was initially located at four ADAS centres: Boxworth, Cambridgeshire; Drayton, Warwickshire; Gleadthorpe, Nottinghamshire; and High Mowthorpe, North Yorkshire. The Gleadthorpe site was terminated after the first year because of an unforeseen variation in soil structure which seriously compromised the effects of nitrogen treatments. The results reported here are restricted, therefore, to the remaining three sites.

The experiment is of a conventional split-plot randomised block design and permits the individual component effects of omitting or reducing nitrogen fertiliser, insecticide, herbicide and fungicide inputs to be studied over the course of various six-year crop rotations. An element of invertebrate monitoring using pitfall traps and D-vac suction sampling is also included, to observe the short-term effects of pesticides on beneficial arthropods.

The main treatments consist of Standard and Alternative (six-course) Rotations subjected to two contrasting regimes of nitrogen and pesticide use: Current Commercial Practice (CCP) or a Low Input Approach (LIA). Standard Rotations are based on a conventional cereal rotation with break crops typical of the locality. They contrast with the Alternative Rotations, which include spring-sown crops with an inherently lower demand for nitrogen and pesticide use than autumn-sown crops (Table 1). Each rotation has two phases; Phase 1 started at the first year in the rotation and Phase 2 started at year 4. Therefore, by the end of the experiment, two sets of data will be available for each crop position in the rotation, which should take some account of seasonal variation.

Table 1. Cropping sequences of the Standard and Alternative Rotations at TALISMAN experiment sites. S - spring-sown crop. W - autumn-sown crop.

Rotation & Year	Boxworth	Drayton	High Mowthorpe
Standard Rotation			
1 *	W. beans	W. oilseed rape	W. oilseed rape
2	W. wheat	W. wheat	W. wheat
3	W. wheat	W. wheat	W. wheat
4 **	W. oilseed rape	W. beans	W. beans
5	W. wheat	W. wheat	W. wheat
6	W. wheat	W. wheat	W. barley
Alternative Rotation			
1 *	S. linseed	S. beans	S. linseed
2	W. wheat	W. triticale	W. wheat
3	S. wheat	W. triticale	S. barley
4 **	S. beans	S. oats	S. beans
5	W. wheat	W. triticale	W. wheat
6	S. wheat	W. triticale	S. barley

* Start year (1991/92) of rotational Phase 1. ** Start year (1991/92) of rotational Phase 2.

The CCP regime is intended to reflect mainstream agricultural practice. The CCP nitrogen rate is determined using the ADAS Fertiplan system of calculating nitrogen demand for each crop based on soil nitrogen reserves, previous cropping and expected yield. CCP pesticide use is based on full rates of use as recommended on the product label. Choice of active ingredient is determined by selecting the most commonly used pesticides, as indicated by the most recent Pesticide Usage Survey (Davis *et al.* 1990) or more recent survey data. Treatment decisions within CCP are made according to crop monitoring and the use of treatment thresholds where they are available, or based on the knowledge of local Site Managers and a Technical Management Team of ADAS Consultants.

Within the LIA regime, nitrogen and pesticide use are restricted by an overall target of reducing the dose rate by at least 50% compared with CCP. Wherever possible, the reduction in pesticides is achieved by omitting applications. However, if it is estimated that a yield penalty greater than 10% is threatened from withholding a particular treatment, then up to half the rate applied to CCP within the same main treatment may be used. In exceptional circumstances, applications at the full rate are permitted within the LIA if there is evidence that the viability of the experiment may be jeopardised. The pesticide products, cultivars, cultivation and sowing dates are the same in both CCP and LIA.

Crop rotation and CCP or LIA nitrogen rate are applied as main treatments to main plots of 24 m x 24 m in a randomised block design with four or five replicates. Superimposed on the main plots are five equal sub-plots to examine and isolate the component effects of herbicides, fungicides or insecticides. The sub-treatments are: all pesticides applied at the CCP rate; all pesticides applied at the LIA rate; and three combinations of only herbicide, fungicide or insecticide at the LIA rate with the remaining two pesticide components at the CCP rate. Main plot treatments are applied using commercial farm equipment. Sub-plot treatments are applied with Oxford Precision sprayers. The crops are monitored throughout the season to measure crop morphology and the incidence of pests, diseases and weeds. Crop yields are measured using plot combine harvesters.

RESULTS AND DISCUSSION

Reduction of inputs

The quantities (weight of a.i.) of nitrogen and pesticide were, as intended, reduced by at least 50% overall in the LIA compared with the CCP regime. The Alternative Rotation has needed a consistent lower usage for nitrogen and pesticides than the Standard Rotation because of the lower input requirement of spring-sown crops generally compared with conventional autumn sown crops (Table 2).

The overall reductions in pesticide use in the LIA have been achieved mainly by cutting application rate rather than omitting applications. Although pesticide units applied (Table 2) in the LIA are normally at least 50% below CCP, the total number of active ingredients applied to the LIA is currently 22% below that of the CCP (Table 3). However, the number of active ingredients applied to winter oilseed rape, winter and spring beans, linseed and spring oats has equalled or exceeded a reduction of 50% in the LIA compared with the CCP. In the predominant crop, winter wheat, a more conservative reduction of 15% was attained owing mainly to a cautious approach in the use of fungicides and herbicides.

Table 2. The effect of rotation and CCP or LIA regimes on cumulative pesticide and nitrogen use 1990-1993. P1 - Rotational Phase 1, P2 - Rotational Phase 2. Figures in parentheses are % difference of Alternative from Standard Rotation averages.

Rotation / Site	Pesticide use (units)*				Nitrogen use (kg/ha)			
	P1		P2		P1		P2	
	CCP	LIA	CCP	LIA	CCP	LIA	CCP	LIA
Standard Rotation								
Boxworth	18.0	8.0	15.0	8.5	360	180	530	265
Drayton	27.0	12.5	29.0	13.5	490	245	324	158
High Mowthorpe	19.0	7.5	15.0	6.0	662	330	414	207
Average	21.3	9.3	19.7	9.3	504	252	421	210
Alternative Rotation								
Boxworth	12.0	7.0	-	-	400	180	-	-
Drayton	22.0	9.0	20.0	8.5	205	103	320	160
High Mowthorpe	15.0	6.5	16.0	6.5	454	223	364	182
Average	16.3	7.5	18.0	7.5	353	169	342	171
	(-24)	(-11)	(-10)	(-17)	(-30)	(-33)	(-19)	(-19)

* One pesticide unit = one full-rate application of a single active ingredient, alone or in mixtures.

Table 3. The effect of crop and CCP or LIA regimes on the average number of herbicide (H), fungicide (F) and insecticide (I, including molluscicide) applications per crop, 1990-93.

Crop (nos. grown)	CCP				LIA			
	H	F	I	Total	H	F	I	Total*
W. wheat (14)	4.2	3.1	0.8	8.1	4.2	2.6	0.1	6.9 (-15)
W. triticale (4)	6.0	0.5	2.3	8.8	6	0	0.5	6.5 (-26)
S. barley (2)	5.0	2.0	0	7.0	5.0	2.0	0	7.0 (0)
W. barley (1)	3.0	3.0	0	6.0	3.0	3.0	0	6.0 (0)
S. oats (1)	2.0	2.0	1.0	5.0	0	2.0	0	2.0 (-60)
S. wheat (1)	3.0	1.0	0	4.0	3.0	1.0	0	4.0 (0)
W. oilseed rape (3)	1.3	1.0	1.7	4.0	1.0	0	0.7	1.7 (-58)
W. beans (3)	1.3	2.0	0.3	3.6	0.3	1.3	0	1.6 (-56)
S. beans (2)	1.0	2.0	1.0	4.0	0	2.0	0	2.0 (-50)
S. linseed (2)	1.0	2.0	1.0	4.0	0	2.0	0	2.0 (-50)
Overall (33)	3.5	2.1	0.9	6.5	3.2	1.7	0.2	5.1 (-22)

* Figures in parentheses are % difference of LIA from CCP

According to the total number of pesticide active ingredients applied, insecticide use in the LIA was 78% below that in CCP although fungicide and herbicide use was reduced by no more than 19% and 9% respectively. The greater reduction in insecticide use reflects the more sporadic nature of pest problems and the greater availability and wider, rigorous use of action thresholds for pest problems. Treatment thresholds for pests have been in use longer than those for diseases or weeds because the environmental consequences of insecticide use and the need for rational decision making in their application was first realised in the 1960s. Effective control of diseases and weeds also often demands a more preventive strategy in the use of fungicides and herbicides.

Although large overall reductions in insecticide use have been obtained in the LIA, the adverse consequences of omitting some insecticide applications were costly, as outlined in the Crop Response section below. Such major penalties did not occur with herbicide and fungicide use, perhaps reflecting a more risk-adverse and conservative approach to their use.

Economic performance

The gross margin data presented (Tables 4 and 5) do not include EU Arable Area Aid payments which came into effect during 1992/93. However, the linseed gross margin includes a subsidy payment that was available in 1991.

With the exception of the Alternative Rotation at Boxworth, the cumulative gross margins of the Alternative Rotation were less than their Standard Rotation counterparts at each site (Table 4). At Boxworth, the Alternative Rotation was improved by the favourable margins of linseed and spring wheat, whilst the Standard Rotation suffered from a poor yielding LIA second wheat caused mainly by a reduction in nitrogen (see below).

Table 4. The effect of rotation and CCP or LIA regimes on cumulative gross margin 1990-1993 (£/ha). Figures in parentheses are % difference of LIA from CCP.

Rotation/Site	Rotational Phase 1		Rotational Phase 2	
	CCP	LIA	CCP	LIA
Standard Rotation				
Boxworth	1638	1586 (-3)	1258	1109 (-12)
Drayton	1447	1411 (-3)	1606	1691 (+5)
High Mowthorpe	2647	2040 (-23)	2353	2194 (-7)
Average	1911	1679 (-12)	1739	1665 (-4)
Alternative Rotation				
Boxworth	1720	1825 (+6)	-	-
Drayton	1164	1260 (+8)	1250	1337 (+7)
High Mowthorpe	2131	1900 (-11)	2183	1925 (-12)
Average	1672	1662 (-1)	1717	1631 (-5)

Within rotations, the cumulative LIA gross margins were all below those of the CCP in the Standard Rotation, with the exception of Phase I at Drayton where the CCP gross margin of the first winter wheat was £160/ha less than that of the LIA. This was mainly due to a lower CCP yield associated with higher levels of lodging (55%) at the CCP nitrogen rate compared with the LIA (5%). However, in the Alternative Rotation, the LIA cumulative gross margins exceeded those of the CCP at all sites except High Mowthorpe, where loss of milling quality price premiums in the first winter wheats of the Alternative Rotation were caused by LIA rate nitrogen (see Crop Response section below).

Apart from winter oilseed rape, the output of the break crops of linseed, beans and spring oats (grown as a cereal break crop at Drayton) was not adversely affected by the LIA regime (Table 5). However, the average gross margin of the LIA winter oilseed rape was below that of the equivalent CCP gross margin and in all three crops of winter oilseed rape the LIA gross margins were consistently below those of the CCP regime.

The LIA gross margins for winter wheat were below those of the CCP in the Standard and Alternative Rotations respectively (Table 5). The half-rate nitrogen applied to the LIA had the greatest impact in lowering yields, particularly in the second-year winter cereals. This was illustrated by the two 1992/93 winter wheat crops at Drayton in which the LIA nitrogen treatment yielded 1.79 t/ha (25%) and 1.94 t/ha (26%) less than the CCP nitrogen treatment in Standard Rotations Phase I and II, respectively ($P<0.05$). Savings made in LIA variable costs were insufficient to compensate for this yield reduction and the equivalent LIA gross margins were consequently reduced by £60 and £85, respectively, compared to the CCP. Similar

Table 5. The effect of rotation and CCP or LIA regimes on mean gross margins of crops grown 1990-1993 (£/ha).

Rotation and crop	Nos. crops grown	Nitrogen & pesticide regime CCP	LIA	% difference of LIA from CCP
Standard Rotation				
W. wheat	11	568	534	-6.0
W. beans	3	655	660	+0.8
W. OSR	3	511	379	-25.8
W. barley	1	638	506	-20.7
Alternative Rotation				
W. wheat	3	860	733	-14.8
W. triticale *	2	299	413	+38.1
S. linseed	2	684	682	-0.3
S. beans	2	657	643	-2.1
S. barley **	4	421	369	-12.4
S. wheat	1	598	616	+3.0
S. oats	1	588	658	+11.9

* Excludes two failed crops caused by slug attack.

** Includes two crops sown after failed w. triticale.

patterns were evident in the yields and gross margins of second cereals of winter wheat and winter barley at Boxworth and High Mowthorpe. However, in the first-year (1990/91) winter cereals at Boxworth and Drayton the effect of reducing nitrogen was not as severe or consistent and spring cereals have been more resilient in their response to the LIA.

Crop response to LIA

Break crops

With the exception of the oilseed rape at Boxworth, the main cause of reduced yield was associated with the LIA rate of nitrogen. At Boxworth, inadequate control of volunteer wheat in a poorly established oilseed rape crop seriously depressed yield which was more pronounced at the LIA rate of nitrogen. At High Mowthorpe, the reduction of nitrogen was the main factor in limiting the LIA oilseed rape yield; reducing the nitrogen from 220 kg/ha (CCP) to 110 kg/ha (LIA) caused a yield reduction of 1.02 t/ha ($P<0.05$). A similar trend was noted in the oilseed rape at Drayton.

Despite the apparent tolerance of most break crops to low inputs, the omission of certain inputs affected yield. For example, an infestation of black bean aphid (*Aphis fabae*) developed on the spring beans at Drayton. In response, pirimicarb was applied to the CCP only, on 10 July 1991. Eight days after treatment the aphid infestation averaged 2% and 88% shoots infested in the CCP and LIA (low-rate insecticide sub-treatment) respectively. A mean yield loss of 0.61 t/ha (15%, £111/ha) was associated with the omission of pirimicarb in the low-rate insecticide sub-treatment. The insecticide was evidently highly cost-effective as the cost of treatment (including application cost) was approximately £15/ha.

Cereal crops

The response of cereals to the LIA was variable and not without problems. Grain quality was adversely affected by LIA rate nitrogen in some cases. The reduced rate of nitrogen resulted in the loss of the milling quality price premium in the LIA first winter wheat (cv. Hereward) of the Alternative Rotation (Phase I and II) at High Mowthorpe. Grain nitrogen content was lower in the LIA (2.0%) than the CCP (2.5%) ($P<0.05$). The sale price of the LIA wheat was consequently disadvantaged by £25/ha.

As with the break crops, omitting certain pesticide applications had a detrimental effect in cereals. This point was again illustrated well by the problems of aphid control. At High Mowthorpe, the first winter wheats (1991/92) suffered from a late-season infestation of grain aphid (*Sitobion avenae*) and rose-grain aphid (*Metopolophium dirhodum*). When assessed at the early dough growth stage (GS 83) the action threshold of 66% ears and/or tillers infested was exceeded. Dimethoate was applied, therefore, to the CCP on 8 July 1992. However, the LIA was not treated as the crop was thought, based on experiment results, beyond the latest growth stage to obtain an economic response to insecticide (late-milk GS 79). Highly cost-effective yield increases of 0.77 t/ha (8%) and 0.63 t/ha (7%) occurred at the full nitrogen rate where dimethoate was applied to Phases I and II, respectively, of the Standard Rotation ($P<0.05$). Smaller, non-significant, increases in yield were noted at the half rate of nitrogen, and similar trends were seen for the winter wheat in the Alternative Rotation.

Slugs were a persistent problem at Drayton in autumn 1992 and severely damaged the triticale in the Alternative Rotation. The winter wheat in the Standard Rotation was less severely attacked. Despite two full-rate, post-emergence applications of methiocarb to the CCP only on 10 November and 4 December, by 7 January 1993 the average plant population in the treated "all high-rate pesticide" sub-plots was 127 plants/m^2. The plant population was lower than this in the untreated "all low-rate pesticide" sub-plots which averaged 61 plants/m^2 ($P<0.05$). Because of the extremely low and variable plant population, the entire triticale crop of the Alternative Rotation was subsequently replaced with spring barley. This incident further demonstrates the potential risks of maintaining a low-input approach to pest control and the difficulties of slug control.

Reducing fungicide rates did not generally cause problems although disease levels have not, as yet, presented a serious challenge to LIA fungicide use. Greater reductions of rate or omission of fungicides may be possible in future. The implications of reducing herbicide use in the first two years of TALISMAN was been considered by Clarke *et al.* (1993). Weed problems associated with a LIA herbicide regime may take several years to accumulate. For example, the carryover of wild oats in the Alternative Rotation at Drayton was much higher following the spring beans than the spring oats. Relatively long-term experiments such as TALISMAN allow slow developing or cumulative problems to be monitored.

CONCLUSIONS

TALISMAN is demonstrating that choice of crop and crop rotation must be carefully considered in the development of low-input systems. Certain crops such as linseed, beans, triticale and spring cereals appear to be more tolerant of lower nitrogen and pesticide inputs. Rotations dominated by spring crops rather than winter crops may be more compatible with the implementation of IPM in arable systems. Reducing nitrogen caused some large yield reductions, particularly in oilseed rape, winter wheat and winter barley. The associated savings in pesticide costs were not always sufficient to maintain profitability. These findings illustrate that the arbitrary 50% reductions in nitrogen use applied to the LIA regime were not suitable for all crops. However, it may be possible to optimise nitrogen application more accurately using techniques such as crop canopy management of winter wheat. This is currently the subject of UK research funded jointly by the Ministry of Agriculture, Fisheries and Food (MAFF) and industry under the LINK scheme.

The Low Input Approach in TALISMAN remains largely dependent on the conventional use of pesticides. Reductions in pesticide use have been brought about more frequently by the use of reduced rates than by the gross omission of applications. However, large reductions in overall pesticide use have been achieved without major economic penalties in many cases. Greater risks have been taken, and substantial financial penalties incurred more frequently, with the control of invertebrate pests than with diseases or weeds. These observations suggest that any unwillingness of crop protection consultants or farmers to adopt action thresholds is a reflection of the potentially large financial losses at stake and, in many cases, technical uncertainty surrounding the thresholds.

There is scope to further reduce pesticide use in a true IPM system, particularly by reducing the prophylactic use of fungicides and herbicides. The technical requirements and problems encountered with pesticide use in the LIA regime have reflected gaps in our knowledge. For example, the yield responses from the late-season control of cereal aphids has challenged the accepted cereal aphid treatment thresholds. Whole system (holistic) studies such as TALISMAN, therefore, serve to identify subject areas within IPM that require further study.

Threshold-based decision making for invertebrate pests, diseases and weeds must be developed further and refined before the risks of IPM become commercially acceptable.

The TALISMAN experiment, although lacking full integration of cultural and biological control measures, is providing many indications of the practicalities of implementing arable IPM. Consistent reductions of at least 50% in the dose rate of pesticide applications have been a more reliable and lower-risk method of reducing pesticide use than the omission of applications. The results so far indicate that profitable reductions in nitrogen and pesticides are possible, provided they are targeted selectively. The study is confirming that the principles of IPM entail a higher risk and lower safety margin when safeguarding the profitability of arable crops. It is likely that successful arable IPM systems of the future must be founded on a flexible policy when applying the most appropriate inputs, which will demand a high degree of knowledge and management skill. Large scale, multi-disciplinary, replicated experiments such as TALISMAN, gathering data on a many different variables, can, therefore, make an an important contribution in bridging the gap between research and the implementation of IPM systems in arable crops.

ACKNOWLEDGEMENTS

The authors thank the many ADAS staff who have participated in TALISMAN. The financial support for this work by the Ministry of Agriculture, Fisheries and Food (MAFF) is gratefully acknowledged.

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A FIRST-STAGE INTEGRATED PEST MANAGEMENT SYSTEM FOR KIWIFRUIT

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ABSTRACT

Kiwifruit in New Zealand is grown entirely for export. The principal pests (armoured scale insects and leafrollers) have historically been controlled using a regular schedule of broad-spectrum insecticides. However, an increasing proportion of the industry (12%) is now adopting a first stage Integrated Pest Management system based on monitoring key pests. During the growing season this system specifies insecticides (mineral oils and *Bacillus thuringiensis* products) that are exempt from residue requirements. Limited use of diazinon is permitted immediately after flowering. Scale insects are monitored by measuring the percent of leaves infested with live scale, with an action threshold of 4%. Leafroller control relies on a preliminary threshold of 2% of fruit with live caterpillars or fresh damage.

Future developments are discussed.

INTRODUCTION

A key factor in the development of kiwifruit (*Actinidia deliciosa* cv. 'Hayward') as a commercial crop in New Zealand has been an emphasis on the production of high quality fruit. The New Zealand kiwifruit industry has striven to produce fruit without defects and which also meet the phytosanitary requirements of our international markets. Until recently, this has been achieved using calendar spray programmes to control pests.

As kiwifruit is a new and unique fruit it has been difficult to establish maximum residue levels for pesticides across all markets. This has restricted the range of insecticides that growers can use to several organophosphate materials and the synthetic pyrethroid, permethrin. A residue monitoring programme was set up early in the development of the industry, and a requirement that, at harvest, growers must submit a copy of their spray diary before their crop is accepted for export. The residue monitoring has shown a very high level of grower compliance with with-holding periods, ensuring that residue levels have been well within allowable levels (Holland *et al.*, 1986).

Industry leaders in the mid-1980's recognised the need for, and began to fund, research aimed at developing Integrated Pest Management (IPM). The reasons for this included wanting to broaden the range of control options available, to avoid secondary pest outbreaks resulting from predator or parasite disruption, to prevent the development of insecticide resistance and to minimise harmful effects on the environment. When, in 1991, access to a market was threatened by increasing consumer and legislative concerns about residues, this previous research enabled the industry to develop a commercial system to produce fruit without detectable residues of conventional pesticides. This system, known as the KiwiGreen Project, is a prototype or first-stage IPM programme (Prokopy *et al.*, 1990).

Thus for kiwifruit, IPM has been driven by commercial need, and the resultant system reflects the constraints imposed by the conflicting demands of consumer pressures for less residues, but high cosmetic quality, and quarantine requirements for freedom from pests.

This paper describes the initial and future development of this system, and its implementation.

PRE-KIWIGREEN

In the late 1960's when kiwifruit began to be grown commercially in New Zealand, few pests were known. Over the next 15 years as the area growing kiwifruit expanded, and orchards matured, pest problems increased and spraying intensified. The spray programme recommended to growers became a schedule applied every 3-4 weeks from before flowering in November until harvest in May.

The key pests of kiwifruit in New Zealand are three armoured scale insects (greedy scale *Hemiberlesia rapax*, latania scale *Hemiberlesia lataniae* and oleander scale *Aspidiotus nerii*) and a number of leafrollers (Steven, 1990). The principal leafroller pests are endemic species, the brown-headed leafrollers *Ctenopseustis obliquana* and *C. herana*, and the black-lyre leafroller *Cnephasia jactatana* (Steven, 1992).

Secondary insect pests include two species of *Stathmopoda*, the caterpillars of which cause damage which resembles that caused by leafroller caterpillars, and the passion-vine hopper *Scolypopa australis* (Steven, 1990). The presence of two-spotted mite *Tetranychus urticae* overwintering on the fruit has caused the fumigation of fruit arriving in Japan, and oribatid mites and the collembola *Xenylla maritima* have sometimes caused quarantine problems (Steven, 1990).

STEPS TOWARDS IPM

Initial progress

Early studies showed that most leafroller damage to fruit occurred immediately after flowering, so that fewer, better-timed sprays could control these pests; however trials to better time sprays against scales gave variable results (Steven, 1990; Wearing *et al.*, 1980). Further improvements in our understanding of the phenology of key pests has identified unnecessary applications which could be omitted (Blank, 1980; Stevens *et al.*, 1993).

Two-spotted mite - biological control

Kiwifruit vines are not a preferred host for this mite, but large populations can develop on susceptible shelter trees (especially willows *Salix* spp. and poplars *Populus* spp.), or weeds such as black nightshade (*Solanum nigrum*) or white clover (*Trifolium repens*). From there the crop can be invaded. The predator mite *Phytoseiulus persimilis* was introduced from France and distributed throughout New Zealand in the early 1980's. Subsequent research showed that in kiwifruit orchards the predator populations did not respond rapidly enough to two-spotted mite increases to prevent overwintering pest mites accumulating on the fruit. A system was developed in which predators from commercial suppliers were released onto problem shelter-belts in January each year. This gave excellent control (Charles & Geddes, 1991).

Scale insects - monitoring and thresholds

In the late 1980's, the New Zealand Kiwifruit Marketing Board (NZKMB) funded trials to develop a monitoring and threshold system for scale insects. Leaves were sampled because on leaves scale insects are more easily seen, and populations are higher. Initial samples used one leaf per vine. The leaves were examined microscopically and the percentage infested with live scale insects determined.

A range of action thresholds from 1% to 16% were tested over a 4-year period. Although there were some indications that scale insect infestation on the fruit increased as the threshold rose, the crops produced met commercial grading standards (Steven *et al.*, 1992).

Selecting suitable spray materials

A second component needed to produce kiwifruit free from residues of conventional insecticides was to identify materials which were either exempt residue requirements, such as products containing Bt (*Bacillus thuringiensis*), or which were too short-lived to leave detectable residues at harvest. Our experience from limited trials on kiwifruit to develop organic pest controls, that is those acceptable under IFOAM standards, indicated that a programme based on Bt and mineral oil would work. These materials were used exclusively after fruit set in the first year of KiwiGreen. In the two subsequent seasons, growers have had the option of using one or two diazinon sprays between flowering and the 10th January.

The introduction of petroleum oils to control armoured scales has been an important step towards IPM. Early trials with oils applied to dormant vines or during the growing season showed that they could cause phytotoxicity (Ford, 1971; Sale, 1972). These problems have been overcome by the subsequent development of more highly refined oils and the identification of factors influencing damage on kiwifruit (McKenna & Steven, 1993).

FIRST STAGE IPM - KIWIGREEN

When the protocol for the pilot scheme was drawn up, the 4% threshold for scale insects was chosen as this offered the potential to reduce spraying with minimum risk of control failing. Higher thresholds used fewer sprays, but the risk of obtaining inadequate control was greater. This conservative approach also took into account that the spray materials available under a residue-free regime was less potent than the conventional chemicals used in the development trials.

The basic KiwiGreen spray programme allows a participating grower to use any registered insecticide before flowering. Only Bt and oil can be applied during flowering to avoid killing honeybees. Immediately after flowering sprays of Bt and diazinon are applied to control leafrollers. Then monitoring begins and subsequent sprays are only applied if thresholds are exceeded. The scale insect threshold is 4% of leaves infested with live scale insects; for leafrollers fruit are examined for caterpillars or fresh damage and a 2% threshold used.

INDUSTRY UPTAKE AND BENEFITS

The success of this first-stage IPM system is shown by the rate of industry uptake. The pilot scheme in 1992 involved 23 growers committing 50 ha of orchard and resulted in 260,000 trays of fruit being produced. The following season the programme spread to 280 growers, involved 1,000 ha and produced 4,700,000 trays. In 1994 330 growers used the system and harvested 6,800,000 trays - 12% of the national crop of kiwifruit.

Growers volunteer to participate in KiwiGreen without being offered a premium for the fruit. They may or may not reduce spraying costs, as the new materials are more expensive than conventional insecticides. The cost of establishing the sampling services has initially been borne by the NZKMB, but will be devolved to growers in future. The benefits to growers have arisen from a better living and working environment, and retaining a valuable market at a time when increasing competition has dramatically reduced sales.

FUTURE DEVELOPMENTS

This first-stage IPM programme is still capable of considerable refinement and improvement to make it more efficient and cost effective. The best way to achieve this is from a close interaction of researchers, samplers and growers. The extent of sampling could be reduced in a number of ways (e.g. sampling fewer leaves, using longer intervals, or representative blocks), but would require a sound knowledge of the local situation first to minimise the risk of not identifying a pest outbreak.

A full IPM programme for kiwifruit should include a greater use of biological control agents and a more diverse range of control options, such as plant resistance, better timing, alternative chemicals, and better application technologies. Appropriate controls for the secondary pests also need to be developed. Some research is under way.

Biological control

The critical requirement for improving the control arising from parasites and predators is a reduction in the use of broad-spectrum insecticides, such as we are now achieving.

The armoured scale insect pests of kiwifruit are introduced insects with better potential for improved biological control than the leafrollers, which are endemic. A mite *Hemisarcoptes coccophagus*, which feeds on the scale insect species, was introduced into New Zealand in 1987. It has now been established in a few sites for 4 years, and has shown some potential to reduce scale insect populations (Charles *et al.*, 1994). However, the normal vector for this predator mite, ladybirds of the genus *Chilocorus*, failed to establish so that spread of the mite will have to be managed.

The potential to augment the guild of parasites attacking the leafroller grouped has been little studied.

Better selective controls

There is a clear need for a wider range of selective control measures, using both chemicals and techniques such as mating disruption. Although in New Zealand mating disruption has shown good potential for an introduced leafroller pest of apples (Suckling & Shaw, 1991), this species is unimportant on kiwifruit. Current trials against the key kiwifruit leafrollers using two pheromone blends have shown suppression but not adequate control (Steven & Stevens, unpublished).

Insect growth regulators have shown considerable potential as selective insecticides against leafrollers and armoured scale insects on kiwifruit (Stevens & Steven, 1994; Tomkins *et al.*, 1994) and one product (buprofezin) is already registered for use pre-flowering.

Spray timing

A key factor in the successful adoption of mineral oils has been the identification of periods of crop sensitivity to such products. Applications can be timed to avoid these periods, or other steps taken to minimise the risk of damage if a spray is needed then, e.g. using lower rates (McKenna & Steven, 1993).

Better timing of insecticide applications will become more critical in two ways. Timing is essential with insect growth regulators which are only effective against particular life stages. Spray selectivity can also be improved through careful timing of applications. With increasing knowledge of the pest-beneficial interactions, we are likely to find application windows which give increased selectivity, and so minimise the disruption of natural enemies.

The leafrollers have overlapping and indistinct generations in the major kiwifruit-growing districts. In contrast, the armoured scale insects have more distinct generations, but with a long period of egg production. A model that successfully predicts the phenology of greedy scale (Greaves *et al.*, 1994), is currently being extended both to the other scale insect species, and to an important parasite, *Encarsia citrina*.

Plant resistance

Selection of kiwifruit and shelter plants with lower susceptibility to pests is a long-term process, especially as kiwifruit vines can take 7 years to reach full production, and will last over 30 years. The kiwifruit industry in New Zealand currently depends on a single variety for all of its export. Potential exists to improve the pest resistance in the crop (Tomkins & Steven, 1992).

There are also projects to incorporate Bt toxin genes into kiwifruit plant using genetic engineering.

Post-harvest disinfestation

A full IPM programme could well supplement field control measures with suitable post-harvest disinfestation techniques to ensure that the most stringent phytosanitary requirements are met. Both armoured scale insects and leafroller larvae are killed during cold storage of fruit, provided the period is long enough (Tomkins *et al.*, 1989; Waddell *et al.*, 1990). Potential exists to use modified atmospheres to enhance this process. Heat treatments are another possibility which would fit an IPM approach.

CONCLUSIONS

Although kiwifruit is a new and relatively minor crop on the world scene, the successful development of a first-stage IPM programme for it does illustrate points of general significance. One of the prime lessons is that, given a clearly identifiable need, a well-organised industry can respond rapidly even if major changes are required. With kiwifruit in New Zealand it has taken only 3 seasons for one-eighth of the national crop to be grown using a first-stage IPM programme, instead of a regular calendar spray schedule. This has occurred without any direct financial incentive such as a premium or subsidy, other than the industry itself funding the initial scouting service. The participating growers have borne the risk of any losses from pest damage resulting from a system failure.

Rapid progress has also been possible because previous research had derived , over a number of years, the information with which a new system could be built. This had been partly funded by industry. The development of any IPM programme is a stepwise process dependent on a sound knowledge of the biology and ecology of the principal pests. Further progress hinges on obtaining similar information on the natural enemies of these pests.

ACKNOWLEDGEMENTS

The authors wish to thank NZKMB for faith and funding; the many growers on whose properties trials have been conducted; and Mr D. Allan, Mr G. Gill, Ms C. McKenna, Mr M. Olson, Ms P. Stevens, Ms C. Thomson and Mr D. Wilson for technical assistance.

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COOPERATION - A KEY FACTOR FOR IMPROVED PEST MANAGEMENT ?

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ABSTRACT

The need for improved pest management practices that reduce reliance on chemical pesticide use is increasing while resources for research and extension are declining. A key factor in resolving this problem is increased cooperation between farmers, consultants, extension agents and research scientists, that cross discipline and institutional barriers. Activities within the Cooperative Research Centre for Tropical Pest Management, and particularly the use of problem specification workshops, illustrate how cooperation can be achieved in practice.

INTRODUCTION

Since the advent of pesticides as a major weapon in the battle against pests, many approaches to the scientific philosophy and methodology of pest management have evolved. Integrated pest management (IPM) is the most notable of these, aiming to promote management processes that utilise those agro-ecosystem features that supress pests, that are environmentally safe, sustainable and capable of being integrated with other farm practice. Over the last 25 years, numerous IPM projects have been embarked upon, ranging from local efforts to national (e.g. Huffaker, 1980) and international (Matteson et al., 1993) programs.

It has to be recognised that success in implementing IPM has been very variable, at least in so far as we can evaluate success. This is not unusual - all research and development work is risky - the pesticide industry know this better than most. The important question - that forms the basis for this paper - is how can we improve the rate of IPM success ?

In attempting to answer this question, the paper outlines an approach to IPM that is inter-disciplinary, participatory and uses problem specification as a key part of the process. How this can be implemented in practice is illustrated by recent experience with the Cooperative Research Centre for Tropical Pest Management in Australia.

THE PROBLEM

One way to approach the question of how to improve IPM success is to explore the reason why there have been failures. Although the quality of IPM research and development effort is important, I would argue that an equally important factor affecting IPM success is the methodological framework in which this research and development is carried out. This, in turn, is conditioned by the prevailing scientific paradigm (Perkins, 1982) and the institutional context in which the research and development is conducted.

In my view, a major flaw in the conventional approach to IPM is its excessive emphasis on a science driven approach, based on the traditional technology transfer model. According to this model, basic research leads to the development of novel control methods and practices, that are then relayed to extension services, resulting in farmer adoption. The critics of this approach (Chambers et al., 1989; Kemmis, 1988; Lim, 1992) advocate a different model, incorporating an inter-disciplinary approach and involving the active participation of farmers and other relevant stakeholders.

Before considering how an interdisciplinary and participatory approach to IPM can be implemented in practice, let us first consider three case studies of successful IPM, and the factors that contributed to their success.

CASE STUDIES

The three case studies concern citrus in Australia, vegetables (leeks) in the UK and rice in SE Asia.

Case 1 - Citrus IPM in Queensland.

Over 80% of citrus growers in Queensland have adopted IPM practices, including pest monitoring and the purchase and release of beneficials. In most cases, the stimulus for adopting these practices was the development or perceived risk of pesticide resistance in the major pest - red scale (Cox, 1993). The success of this program can be attributed to a number of critical factors -

* a well targeted, applied research strategy to determine and implement classical biocontrol of the key pests - scale insects, and to develop other key components of the overall IPM package

* development of critical support services in the form of pest monitoring services and the establishment of a commercial rearing facility for beneficials

* excellent rapport between the QDPI entomologist - Dan Smith - the major citrus growers in the region, and an independent crop consultant - Dan Papacek - who also produces beneficials.

Case 2 - Cutworm control in the UK

Cutworms can cause major losses to leek crops in the Thames Valley region in the UK. To improve the timing of pesticide application, a day-degree model was used to predict when the third instar larvae were most abundant, this being the most susceptible life stage of the pest. During an investigation of the performance of this forecasting device on various farms, Taylor (1984) became aware of two important facts -

* that if heavy rainfall occurred after the larvae hatched, mortality was very high

* if there was little rain after transplanting leeks, most growers used overhead irrigation.

Putting these two items of information together, Colin Taylor suggested that the forecast could be used for predicting the optimal time to irrigate and destroy cutworm larvae. Since he was working closely with an independent crop consultant - Ian Gillott - and vegetable growers, this practice is now widely used in the Thames Valley.

Case 3 - Rice pest management in SE Asia

The successful FAO program for rice pest management in SE Asia (Matteson et al, 1993) is based on a strategy of informal farmer training. Another approach to improving rice farmers' pest management practices has been developed by KL Heong at the International Rice Research Institute. This approach is to encourage farmers to join in a critical experiment - to set aside part of their rice crop to see what happens if they do not spray until after 40 days after sowing. This experiment has now been repeated by numerous farmers, particularly in Vietnam and the Philippines, with the result that they have largely adopted delayed spraying as common practice. The idea for this farmer experiment arose out of research studies and numerous field trials indicating that -

* damage caused by early season pests, such as leaf folder, is most unlikely to lead to yield loss due to compensation by the rice plant

* early season sprays with broad spectrum chemicals can cause disruption to beneficial insects and lead to resurgence of pests, such as the brown planthopper.

These three examples all demonstrate the need for involving farmers and other stake-holders as an integral part of the research and development process, and the need to understand key biological and farming system features to achieve practical success. The challenge is to learn from these lessons and apply the principles to other pest problems.

THE CHALLENGE OF IMPROVING PEST MANAGEMENT

All pest problems arise through the interaction of natural and human use (e.g. agricultural) systems. Therefore, the status of the problem and the constraints and opportunities for improved management are influenced by variables within and that have an influence on both systems.

When tackling a pest problem, the initial challenge is to identify the key components and processes in both the natural and human use systems that determine pest status and the opportunities for and constraints to improvement. For instance, what key features of the agro-ecosystem involved and of the pest life-system have most influence on population levels and on the efficacy and sustainability of pest management methods ? How are these key features likely to change over the next 5 to 10 years as agricultural development proceeds, as marketing opportunities change, policy measures are enacted, and technological developments occur ?

To meet this challenge, and to empower the major stakeholders, I would suggest that IPM research and development strategies need to -

* adopt an inter-disciplinary approach, involving socio-economic and political analysis, as well as ecological and technical inputs

* actively involve farmers and other major stakeholders, providing a conduit for a two-way flow of ideas and information between research and practice

* incorporate problem specification processes as an integral part of the research and development effort

* implement the above, together with the technical components of research and development, as parsimoniously as possible to achieve practical improvements in pest management.

An even greater challenge is to implement this approach in the face of discipline and institutional barriers and in situations where research and extension activities are undertaken by different organisations. Although these constraints can cause serious limitations, I believe that a cooperative approach will be seen increasingly as the way ahead, particularly where declining research and extension resources are the norm. To illustrate how institutional arrangements and operational procedures can be used to achieve a cooperative effort, I shall briefly describe the strategy being developed at the Cooperative Research Centre for Tropical Pest Management.

THE CRC FOR TROPICAL PEST MANAGEMENT

The Cooperative Research Centre for Tropical Pest Management (CTPM) was recently established as one of 50 Centres in the Australian Government's Cooperative Research Centre Scheme. The resources of the Centre consist of in-kind contributions - staff and facilities - from four partner institutions and funding from the Federal Government. The four institutions involved are -

* Queensland Department of Primary Industries
* Queensland Department of Lands
* CSIRO Division of Entomology
* The University of Queensland.

Each of these institutions brings different expertise and strength to the Centre: the University and CSIRO are strong in basic research, the two Queensland Government Departments are strong in applied research and extension. The Centre involves over 80 scientists and has a number of collaborative arrangements with other organisations.

The Centre's mission

The mission of the Centre is *"To develop new approaches for improved and sustainable management of tropical pests through a cooperative and integrated program of research, education, training and implementation".* To achieve this, we have developed a strategy that is based on three corner-stone activities, crucial for any attempt to achieve effective and sustainable improvements in pest management -

* clear specification of the pest problem and what is required to realise improvements

* key generic and applied research programs that develop the scientific basis for improving pest management and applies it to specific problems
* communication, education and training activities to convey our scientific output to those responsible for implementation.

The Centre's research strategy

The main focus of CTPM research is on providing the scientific basis for improving the management of pests and associated pest control technologies. Seven research programs are aimed at key activities involved in pest management (Table 1), ranging from the precise genetic identification of pest and biocontrol organisms to the socio-economic evaluation of pest management practices.

The detailed sub-projects carried out by the Centre within these seven programs are also grouped into two types of project. Generic projects are concerned with developing general theories, principles and tools. Applied projects are concerned with specific pest problems or pest complexes on specific crops.
Clearly, within this framework, there is opportunity for a valuable interaction between projects aimed at generic issues and those focusing on specific problems. For instance, a major activity within the Decision Analysis and Implementation program is to undertake case studies of IPM adoption and sustainability in specific crops. Already, the output from these specific studies is contributing to a generic project - to derive lessons and principles on how best to implement and support IPM, which can then be applied to other situations. Thus in this program, as in all the others, we are attempting to achieve a balance between basic and applied research projects that address long- and short-term goals, respectively,

The Centre's implementation strategy

The Centre contributes towards real improvements in pest management by achieving better targeting of applied research and improving the delivery of knowledge and information to key decision makers, whether they be farmers, advisors or policy makers. The Centre's education and training programs, software development and publications all contribute to the latter. The active participation of "end-users" in helping to improve research targeting also provides a communication function; it is on this process that I shall now concentrate.

Table 1. The seven research programs of the CRC for Tropical Pest Management

Research program	Target activity	Disciplines
Insect identities and behaviour	Genetic variation, host specificity, attractants, pheremones	Population genetics, organic and synthetic chemistry, insect behaviour, entomology
Insect/plant interactions	Pest damage, weed biocontrol agent damage	Entomology, computer science, agronomy
Modelling	Pest risk assessment, design of pest management strategies	Computer science, entomology, ecology
Field analysis and application	Problem specification, integration of pest management methods	Entomology, ecology, agronomy
Decision analysis and implementation	Problem specification, adoption/decision making process, community involvement, evaluation	Extension, economics, sociology, policy analysis
Computer assisted learning and decision support	Decision making process and skills	Computer science, information technology, entomology
Biocontrol	Classical insect and weed biocontrol, inundative release	Entomology, ecology, weed science

PROBLEM SPECIFICATION

One of the major reasons many IPM programs do not result in practical improvements in farmers' fields is the lack of effort devoted to gaining a broad appreciation of the problem at an early stage (Norton, 1976; Norton and Mumford, 1993). What is needed is a clear specification of the political, community, and socio-economic dimensions of the problem, as indicated above, to provide inputs to the research and development strategy.

The Centre's approach is to conduct problem-specification workshops for the pest problems we are working on. These professionally facilitated and structured workshops encourage wide participation and provide a basis for the development of a comprehensive strategy for tackling the problem, involving research, development, extension, implementation, and training components.

There are three stages involved in a problem-specification workshop. During stage 1, knowledge, experience and information are provided by participants within structured group-sessions to determine historical profiles, future scenarios, and related opportunities and threats. Stage 2 details the options for improving pest management and the likely constraints. Stage 3 builds on the previous sessions to analyse what needs to be done to improve pest management, and to specify the action plans for achieving this.

A number of problem-specification workshops have been facilitated by the Centre, covering a range of problems, including parthenium weed in tropical pastures, fruit spotting bug in tropical fruits, and pests of raingrown cotton. This last topic, for which two workshops have now been organised (Anon., 1993; Murray et al., 1994), involved cotton growers, consultants, extension and research scientists and chemical industry representatives.

An exciting outcome of the first cotton workshop was the initiative taken by consultants and growers to design their own "IPM trial", to complement the longer-term research on beneficials being conducted by scientists from the Queensland Department of Primary Industries (QDPI). The result is a two-prong research strategy, with QDPI scientists developing and testing novel control methods - particularly the rearing and release of beneficials - and consultants, assisted by QDPI/CTPM staff, investigating more immediate options for improvement - including higher pest thresholds, monitoring beneficials, and using "softer" chemicals. Thus, problem-specification workshops already have become an integral part of our participatory, action research strategy.

CONCLUSION

It has been argued in this paper that to improve the success rate of IPM adoption we need to develop innovative strategies involving cooperative institutional arrangements and participatory processes. If we achieve genuine cooperation between scientists, advisors, farmers and other important stakeholders, the result will be better targeted research, consideration of adoption questions right from the beginning, and greater access to a wide range of required expertise beyond any one organisation's capability. The cooperative arrangements and problem specification workshops of the CRC for Tropical Pest Management illustrate one way in which this approach can be implemented. With the prospect of further reductions in research and extension resources, combined with an increasing emphasis on biotechnological solutions, such as transgenic crops, the need for this cooperative approach will be even more pressing in the future.

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Session 3C

Plant Health and International Trade

Chairman	Dr D L Ebbels
Session Organiser	Mr A W Pemberton
Papers	3C-1 to 3C-5

TRADE AND PLANT QUARANTINE

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ABSTRACT

The GATT Sanitary and Phytosanitary Agreement encourages Members to follow harmonized standards in their implementation of phytosanitary measures. The major principles included in the Agreement include transparency, scientific justification of risk assessments and non-discrimination.

Implications of the agreement to GATT Members are:

— Initially, plant quarantine officials should ensure a careful input into the formulation of standards by taking full part in the FAO consultative process. Subsequently, officials will need to screen national regulations to ensure alignment with international standards (or be prepared to justify differences from standards).
— The emphasis on the justification of phytosanitary measures means that plant quarantine agencies will require increased resources to manage the risk assessments involved.
— Members will require to set up notification procedures to inform GATT of regulation changes if this is not already carried out.
— The national industries of Members will need to be informed of the international standards that might affect national regulations.
— As standards are developed, Members will need to be prepared for involvement in dispute settlement procedures.

INTRODUCTION

The signing of the Uruguay Round of the General Agreement on Tarifs and Trade (GATT) and its imminent ratification has major implications for those involved in phytosanitary and sanitary matters. In the phytosanitary area, all phytosanitary officials and most plant industry personnel involved in the export and import of plants and plant products will feel the impact of the Agreement on the Application of Sanitary and Phytosanitary (SPS) Measures resulting from the GATT Uruguay Round. This paper aims to describe the nature of this impact and the activities of FAO in supporting the intent of the Agreement.

The SPS Agreement includes major principles that will help the implementation of practices that will liberalize trade and reduce discrimination. Many of these principles are included in the International Plant Protection Convention (IPPC) (FAO, 1992; Hedley, 1992). The Agreement encourages: transparency by requiring Members to publish all regulations and inform GATT of regulation changes in certain circumstances; the basing of all measures on scientific principles, including the use of risk assessments; the use of the principle of equivalence; and the application of measures so that there is no arbitrary and unjustifiable discrimination between Members of the GATT where the same conditions exist.

At the request of GATT Members, the FAO Conference has established the Secretariat of the IPPC to facilitate the formulation of international standards for phytosanitary measures. The Secretariat is to be concerned with the production of standards, information management, the strengthening of Regional Plant Protection Organizations (RPPOs), and technical assistance in the quarantine area.

The implications of these principles and the Agreement as a whole are discussed under the following headings:—

— Formulation of Standards
— Justification of Standards
— Notification
— Information Dispersal
— Dispute Settlement

FORMULATION OF STANDARDS

The process for this formulation, agreed upon by the 25th Session of FAO Conference, was essentially an interim system which utilizes the IPPC Secretariat, advised by a panel of experts, together with the FAO Governing Bodies. The Committee of Experts on Phytosanitary Measures (CEPM) was set up under Article VI 2 of the FAO Constitution at the 27th Session of FAO Conference in 1993. The CEPM serves to make recommendations to the Secretariat on the development and acceptability of proposals for the harmonization of standards at various stages of their development and to recommend them for acceptance by the FAO Governing Bodies serving to approve the standards, ie the FAO Committee on Agriculture (COAG), FAO Council and FAO Conference.

The production of international standards for phytosanitary measures has three phases; preparation, consultation and approval. The first phase involves a small working group of experts that prepares a draft for each standard (arranged by FAO or an RPPO as with the preparation of the "Guidelines for Pest Risk Analysis"); the second involves all FAO Members in the consultation exercise; and the final approval phase involves the FAO Governing Bodies mentioned above. The process to have a standard endorsed by FAO Conference takes a minimum of three years.

The consultation phase offers all FAO Members the opportunity to express their comments, ideas and requirements concerning the draft standard. It is essential that Members take a full part in this process. With some standards, there may be more than one round of consultation required. It is hoped that all significant points of issue can be dealt with before the approval phase begins. National Plant Protection Organizations (NPPOs) will need to be prepared to spend time on the examination of and to comment upon the draft international standards.

JUSTIFICATION OF STANDARDS

Following the formulation of international standards for phytosanitary measures, NPPOs will need to ensure that their national regulations are aligned with the standards. With some NPPOs this may not constitute a problem, with others it may. It should be noted that GATT Members are not required to change their level of protection but where this level is higher than that achieved by using the relevant international standard, they may be required to justify the level of protection they find appropriate by means of a scientific risk assessment. There is a likelihood of this occurring where a Member believes that the measures introduced by another Member are constraining trade and are not based on international standards (see Article 5 section 8 of the GATT SPS Agreement).

Thus, where an exporter wishes to export a product to another country, but is prevented from doing so by a prohibition or seemingly over-stringent import requirements, then it is likely the NPPO of the prospective importing country will be asked by the NPPO of the exporting country to justify its requirements. If not already available, a complete pest risk analysis will have to be undertaken. In the case of a developing country, special and differential treatment is available whereby the Committee of Sanitary and Phytosanitary Measures of the World Trade Organization will be able to grant specified time-limited exceptions from obligations under the Agreement.

There will be a heavy reliance on pest risk analyses for the formulation and justification of import regulations. NPPOs will need to have resources to employ the skills of trained risk analysts with appropriate biological and economic experience.

NOTIFICATION

One of the requirements of the SPS Agreement is that Members publish their phytosanitary regulations. This is also a requirement under the IPPC along with advising "...FAO, any regional plant protection organization of which the contracting party is a member and all other contracting parties directly concerned." (Article 6, section 2(b)). These requirements are presently not followed by all Members (Van der Graaff & Ikin, 1993).

The process of notification that the SPS Agreement outlines refers to the case where a proposed regulation is substantially different from the standard, or where a standard for the subject area involved does not exist, and requires that the Member publish the proposed changes and notify other Members through the GATT Secretariat. This is meant to allow comments on the proposals to be taken into account by the Member making the regulatory changes.

It is expected that there will need to be greater emphasis placed by NPPOs on the publishing and notification processes. Each NPPO will have to institute systematic procedures that ensure that its regulations and the updates are readily available to trading partners.

With the development of the Secretariat of the IPPC, it is hoped that a convenient and effective system can be set up which will allow the publishing of regulations and their updates. An FAO system involving computer techniques and networking (such as CD-ROM and Internet) has been discussed by an IPPC Working Group. At present Agriculture Canada, the Inter-American Institute for Cooperation in Agriculture (IICA) and the New Zealand Ministry of Agriculture and Fisheries are investigating prototypes of such a system.

INFORMATION DISPERSAL

The SPS Agreement may affect a number of sectors within each Member country and a NPPO should be prepared to discuss the implications with these sectors (e.g. other Government Departments, industry, extension services, etc.).

The harmonization process should lead to increased export opportunities for many countries. As import regulations are reviewed in the light of the Agreement, risk analyses and international standards, many countries will be able, or be required, to modify their phytosanitary import regulations to allow or ease access to their markets. Such opportunities will be well known to many NPPOs and to some exporters. However, NPPOs should ensure that their industry is fully aware of the changed situation.

Likewise, importers may well be able to increase the number of sources from which they can import produce if there is a rationalization of import regulations of their own country so they are aligned with international standards. NPPOs will need to review their risk analyses, particularly for important commodities, to ensure that unjustifiable restrictions are not limiting the business of importers, and hence the choice of consumers.

An important sector that needs to be aware of the implications of the SPS Agreement is that producing for the domestic market. With the possible relaxation of some import regulations in line with international standards, further imports may be allowed onto the domestic market. Such changes may have significant effects, in the short term, on domestic production systems. NPPOs need to discuss such possibilities with industry personnel to explain the importance of the SPS Agreement and the need to follow its provisions. A comprehensive programme of meetings with industry should be arranged to aim for a rational understanding of how the domestic situation can be affected by international standards.

One major result of the application of the SPS Agreement and international standards will be the diminishing use of phytosanitary measures for industry protection. Domestic industry will need to recognize this fact quickly.

DISPUTE SETTLEMENT

It is likely that, despite the reviewing of regulations to align them with international standards, some countries will feel that some measures of their trade partners still constitute unjustifiable trade barriers. When this occurs, dispute resolution procedures may be initiated. With the availability of standards as international measuring sticks, dispute resolution, by whatever system — arbitration, settlement under the IPPC or the use of a GATT panel — has a much greater chance of yielding useful results than in the past. Members should not hesitate to go to dispute resolution to deal with some of the long-standing problems of trade.

FAO PROGRAMME FOR THE HARMONIZATION OF PLANT QUARANTINE

The success of the SPS Agreement depends a great deal on the harmonization process. If Members are able to align their regulations with international standards, this itself should remove many constraints on trade. In the cases of human and animal life and health, there are a good many standards already in existence; both the Office International des Epizooties and the Codex Alimentarius Commission have been operating for many years. However, this is not the case with phytosanitary standards. Although the IPPC came into force in 1952 (with the Director General of FAO as the depositary) the first standard was not approved until the 27th FAO Conference of 1993 (FAO, 1994). With a Secretariat (of limited size) now established, the FAO has only just begun a programme aimed at rectifying this situation.

As a new standards organization, the Secretariat has had to set up procedures for its staff to operate in the formulation of standards. Systems are required for the operation of the Working Groups, the CEPM (with "Terms of Reference" and "Rules of Procedure", drafted and approved), the consultation process with FAO Members and the preparation of documents for COAG, FAO Council and FAO Conference. Being a standards organization, the IPPC Secretariat will document its procedures, over a period of time, to ensure transparency and consistency of operation.

At the next FAO Conference in November 1995, there could be three standards presented for consideration and approval. These are "Guidelines for Plant Pest Risk Assessment"; "Code of Conduct for the Import and Release of Biological Control Organisms"; and "Requirements for the Establishment of Pest Free Areas". Working groups of international experts are preparing further draft standards concerning various aspects of Pest Risk Analysis, Inspection Methods, and Certification Procedures for submission to the CEPM in May 1995. The standards that are produced at this early stage of development outline the principles involved in the particular area. Following on from these will be more detailed and specific standards that will apply to a defined area of activity, including a specific pest or group of pests, or a commodity. A listing of the possible subject areas for phytosanitary measures was provided by Hedley (paper on Progress towards International Phytosanitary Harmonisation and a Framework for Standards for Phytosanitary Procedures, presented at the Fourth Technical Consultation among Regional Plant Protection Organizations, San Salvador, El Salvador, May 1992). However, despite the urgent need for standards, this limited programme can only be expanded if substantial resources are made available by FAO Members.

Apart from resource problems, the programme is slowed by the time taken for consultation and by the fact that FAO Conference meets only biennially. The Secretariat will be investigating the possibility of using electronic means of communication to facilitate consultation and will initiate a review of the system for the approval of standards.

In support of the standards programme, FAO is aiming to set up an information exchange system that includes electronic methods as well as printed matter. The *FAO Plant Protection Bulletin* is expected to continue but possibly in a modified form to reflect more strongly the aims of the IPPC Secretariat. A computerized FAO Global Plant Quarantine Information System has also been released. As mentioned above, FAO is working towards making available a system that allows the publishing of Members' import regulations and permits their updating.

The IPPC Secretariat will continue to liaise strongly with the Regional Plant Protection Organizations (RPPOs) in the production of standards and the development of information systems. The Secretariat hopes to work with the RPPOs as well to set up training programmes to further the implementation of the standards. As part of its technical assistance programme, FAO will also undertake projects to strengthen national plant protection organizations in developing countries. A number of these have already been undertaken and others are in progress in Cameroon, Dominica, Ghana, India, Malta, Syria and various countries in the Near East.

CONCLUSION

The SPS Agreement offers Members considerable opportunities to develop a trading environment with reduced constraints and better market access. NPPOs need to consider carefully the implications of the Agreement and to develop programmes that take advantage of the new situation.

However, the Agreement does bring added responsibilities. These must be recognized and resources allocated so that they can be met adequately. The task of undertaking risk assessments on a broader basis than has been done previously by most NPPOs will, by itself, make considerable demands on resources.

FAO on its part is making efforts to push forward the harmonization process by facilitating the development of these standards. This process depends greatly on the cooperation of NPPOs (for example in releasing experts to serve on working groups) and RPPOs, as well as on the availability of resources. The support programmes of information management, training, and development assistance, are also considered to be part of FAO's task and are being furthered as resources permit.

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THE POTENTIAL FOR GEOGRAPHICAL INFORMATION SYSTEMS IN ANALYSING THE RISKS POSED BY EXOTIC PESTS

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ABSTRACT

Determining the establishment potential of exotic pests is one of the most complex procedures in pest risk analysis. Since this potential may vary over the area concerned, a map is the most appropriate method for presenting the risks of establishment and predicting the damage costs. To facilitate sampling and control of pests in the event of an outbreak, such risk maps should also be able to predict pest development at the farm and even the field scale. To construct such risk maps, data on the climatic factors influencing pest development must be interpolated between meteorological stations and linked to phenology models. New statistical tools for spatial analysis and geographical information systems provide the procedures necessary for constructing these maps. Where there is limited information on the factors limiting a pest's distribution, world climate databases can provide some indication of establishment potential by enabling comparisons to be made between areas where the pest is known to be present or absent.

INTRODUCTION

The analysis of the risks posed by exotic pests (PRA) is fundamental to the maintenance of an efficient plant health system. Only by conducting a detailed assessment of the risks can optimal strategies for meeting the threat be selected. Once the data have been assembled, various methods for PRAs exist, using written responses, decision trees, scoring systems or probability assessments (Baker & Bailey, 1979; Baker *et al.*, 1992; EPPO, 1993a). The FAO (unpublished) has prepared guidelines to standardise PRAs. Whichever procedure is used, pest risk analysts still have to tackle several complex decisions. One of the most difficult relates to the potential for the pest to become established in the country concerned because so many factors need to be considered (Baker & Bailey, 1979; EPPO, 1993b).

Since establishment may only be possible in certain habitats, in certain regions and in climatically favourable years, it may be difficult to choose an overall score or probability for establishment potential in a particular country. A solution is to produce maps of the areas predicted to be at risk in years of average and extreme conditions. The risk maps can then be used to analyse and cost the potential damage on a regional and national scale and to plan sampling, containment or eradication strategies in the event of outbreaks in particular fields and farms.

In order to create risk maps for exotic pests, a great deal of information has to be assembled, analysed and integrated. At the most basic level, the host plants and their distribution should be known. Determining the suitability of the climate is far more complex since it requires knowledge of the principal climatic factors influencing a pest's development. Once these key factors have been identified, a predictive relationship needs to be determined. Climatic data must also be collected and interpolated from meteorological (met.) stations to areas where the crops are grown. This paper briefly reviews the techniques developed to tackle these problems, concentrating on insect pests and phenology models which describe the relationship between insect development and temperature, the principal environmental variable affecting insect development. Once the relevant data have been assembled, they must be analysed and integrated into usable maps. Geographical information systems (GIS) provide such a facility since they can capture, store, manage, analyse and display spatial and descriptive data (Coulson, 1992).

For many pests, however, there is insufficient biological information to conduct a detailed analysis of establishment potential. The relationship between environmental variables and development may be poorly known or relate only to laboratory conditions. Nevertheless, plant health services may still be required to judge the risk of establishment. In these cases, a comparison of climatic conditions in the countries where the pest is present with areas at risk may be all that is practicable. The potential for GIS in the analysis and display of world climate databases in order to match climates is also assessed in this paper.

GIS AND DETAILED RISK MAPS

Models based on uninterpolated met. station data

For most insect pests, there is a near linear relationship between air temperature and the rate of development except when temperatures are close to the lower and upper development thresholds. Using this relationship, phenology models have been written for many pests which predict the accumulated temperature (AT), measured in degree-days above a defined base temperature, required to complete each life stage, e.g. Baker & Cohen (1985). AT calculations for met. station data representing the country under threat can then provide an indication of a pest's establishment potential and the period of time when it is likely to be at the stage most vulnerable to control measures (Baker, 1991).

The CLIMEX program (Sutherst & Maywald, 1985) also uses a phenology model to predict development. A growth index is obtained for each pest from calculations of AT in seasons favourable for development. This is combined with assessments of stress in periods when conditions are unfavourable to give an ecoclimatic index. These indices can then be mapped to predict development and survival at each met. station for which data is available. Maps of potential colorado beetle (*Leptinotarsa decemlineata*) distribution in the UK based on 1930-1961 met. data from 30 stations were found to agree with expert predictions (Sutherst, 1991), though AT estimates in spring and autumn may be inaccurate since the method recommended by Anon. (1969) is not used.

The principal problem with these predictions is that analysis is restricted to climatic conditions at the met. stations themselves. Met. stations are frequently far removed from agricultural land and are often situated on airfields or in urban areas where climatic conditions are artificially influenced. To circumvent this, field met. stations are increasingly being used by growers to collect data from within crops. While this improves the situation, it still does not take into account the marked spatial variation of climate with topography. In the UK, temperatures decrease at approximately 0.6°C for each 100 m increase in altitude (the lapse rate) and are markedly affected by the slope and aspect of the location in addition to its latitude, longitude and distance from the sea (Smith, 1984; Chandler & Gregory, 1976). To predict the variation in temperatures over the land surface, met. station data must be interpolated.

Climate interpolations

Various techniques have been used to interpolate AT over the land surface in England and Wales. Bendelow & Hartnup (1980) calculated annual AT above 5.6° at 139 stations and drew a contour map of AT by hand using the height contours and the lapse rate to interpolate between stations. Jones & Thomasson (1985) calculated January-June AT above 0°C from 109 stations and estimated the influence of altitude, latitude and longitude by regression to produce averages at 5 and 10 km intervals. An AT contour map was also drawn using height contours. Hallett & Jones (1993) calculated annual AT above 5°C from 87 stations using the method described by Anon. (1969) and interpolated according to altitude, latitude and longitude onto a 5 km grid using quadratic interpolation routines in UNIRAS. These methods provide a useful representation of the variation in AT according to altitude, latitude and longitude country-wide but do not take into account the effect of the distance from the sea and important topographic features such as slope and aspect. It is thus difficult to use these methods to study climatic differences between fields and farms.

White (1979) tackled this problem using principal components and multiple regression analysis on 19 site variables and 21 climatic variables from 68 UK stations. The only temperature regression equations published were those predicting 9 am quarterly screen temperatures (see below). Equations for maximum and minimum temperatures from which approximate ATs could have been calculated were not published.

However, regression techniques are inherently inaccurate as a method of interpolating met. data because they give equal weight to all points, ignoring the substantial autocorrelation which exists between close neighbours (Robertson, 1987). Spatial interpolation techniques such as geostatistics (kriging) and spline interpolation have been developed to take account of this problem. Of these techniques, Laplacian thin plate smoothing splines have been used most widely in interpolating met. data. Hutchinson *et al.* (1992) summarised a study which used this technique to interpolate monthly mean maximum and minimum temperatures across Australia to within a standard error of 0.5°C.

Risk maps using interpolated met. station data

In order to illustrate the potential of GIS in interpolating and displaying climatic data as a precursor to producing risk maps for use in PRAs, White's (1979) equation predicting mean 9am April-June temperatures in a screen 1.3 m above ground was applied to a 20 x 20 km^2 area of the Chilterns 50 km northwest of London. The equation is represented as:

$$T = -0{\cdot}00747ELEV + 0{\cdot}00226SLOW - 0{\cdot}029SENW + 0{\cdot}128\log_e(DFS + 1) + 11{\cdot}4$$

where T is the mean 9am April-June temperature in °C, ELEV is the elevation in metres, SLOW is the slope with east or west aspect in degrees of gradient (westerly slopes counting negative), SENW is the position on a south-east to north-west axis and DFS is the distance from the sea in km.

Digital elevation data at 50 m resolution were purchased from the Ordnance Survey (OS) in National Transfer Format and converted to ASCII format before being imported into GRASS (CERL, 1993) GIS software running on a Sun SPARC station. Slopes and aspects at 50 m resolution were calculated and displayed using commands in GRASS. GRASS provides commands for combining map layers using map algebra and conditional statements. To control data integrity and determine whether data could safely be exported, manipulated and reimported into GRASS, the elevation, slope and aspect layers were exported in ASCII format and imported into separate sheets in a spreadsheet program. SENW was calculated from the eastings and northings of the elevation data and the minimum DFS obtained from a UK 1:625,000 map; both variables being placed in additional sheets. Estimates of T were then obtained using the equation above, exported in ASCII format, imported to GRASS and displayed in three dimensions (see Figure 1).

The effect of elevation on temperature is most apparent, ranging from 11.1°C at 70-100 m on the plain around Aylesbury to 9.6°C at 250 m on the tops of the Chilterns. No attempt was made to test the accuracy of these results, the primary aim being to explore the potential of the technique. In addition, a raster image of the 1:50,000 Landranger map was purchased from OS and imported into GRASS and used to highlight temperatures according to land use. Clearly, once interpolated ATs are available, insect development stages could readily be imported and displayed by GRASS.

Risk maps have already been constructed for some pests and pathogens using these techniques. Russo *et al.* (1993) mapped the predicted daily gypsy moth (*Lymantria dispar*) egg hatch distribution on a 1 km^2 grid in six northwestern states of the USA. Mean monthly maximum and minimum temperatures were interpolated by regression according to latitude, longitude and elevation. Royer & Yang (1991) predicted the potential severity of soybean rust, *Phakospora pachyrhizi*, in the same area with a comparable climatological dataset.

CLIMATE MATCHING

This is the simplest method for predicting climatic suitability, which can be used when information on the pest's biology is limited but its geographical distribution is known. The climate at met. stations near the centre and edge of a pest's natural geographical distribution is compared with the climate at met. stations in the country under threat. Monthly data, such as time series of mean monthly maximum and minimum temperatures, relative humidity and rainfall can be plotted and visually compared. The data can also be plotted as x-y graphs, known as climatographs or hythergraphs, in which data from each met. station form a polygon and favourability is determined by the displacement of polygons from those for stations in areas favourable to the pest (Cook, 1925). Neither method provides a straightforward statistical assessment but may be useful where differences are clear-cut e.g. Baker & Dickens (1993). The climate matching module of the CLIMEX program (Sutherst & Maywald, 1985) also provides graphical comparisons of temperature and rainfall, aligning cold seasons in the northern and southern hemispheres. A match index can be calculated from the product of similarity indices for maximum and minimum temperature, rainfall and rainfall pattern at over 3,000 met. stations worldwide (Maywald & Sutherst, 1991) but this cannot be modified if only similarities in temperature need to be calculated.

AT is the key variable which limits the development of most insect pest species. Baker (1990) was able to identify areas of the world which are climatically similar to the United Kingdom using accumulated temperatures above a base of 10°C. For accurate accumulation of degree-days, daily rather than monthly maximum and minimum temperatures are required and special formulae should be applied when these variables are lower than the base temperature (Baker, 1980; Anon., 1969). Unfortunately, there is no publicly available world climate database with daily rather than monthly data summaries from which accumulated temperatures can be calculated satisfactorily and the most comprehensive databases supply monthly means and not maximum and minimum temperatures.

To illustrate the potential of using GIS to display and analyse global climate databases, monthly mean temperature data with a resolution of 0.5° latitude and longitude were taken from the International Institute for Applied Systems Analysis world climate database produced in GRASS format (CERL & Rutgers University, 1993). These data have been interpolated from 6279 met. stations worldwide using 1931-1960 means, modified to take altitude into account using a standard lapse rate of -0.6°C/100 m (Cramer & Leemans, 1992). Without maximum and minimum temperatures, approximate monthly ATs were obtained by subtracting a base temperature of 10°C from the mean monthly temperatures supplied and then multiplying by the number of days in the month. To avoid problems which arise when mean temperatures are close to the base temperature, AT was only calculated for the five months of May to September. The calculations used map algebra procedures provided in GRASS and displayed for Europe (Figure 2).

Although these approximate European summer ATs show the effect of latitude and altitude as expected, they contain too many innaccuracies to be used to predict European species distributions. New datasets in construction will resolve some of these problems and improve the prospects for predicting species distributions worldwide.

CONCLUSIONS

Although spatial statistics and GIS have only just begun to be used in predicting the distribution of exotic pests in PRA, they have considerable potential. Current phenological models can only simulate development at the met. stations where climatic factors have been recorded. With climatic data interpolated according to topography between met. stations, predictions for individual farms and fields can be made for use in sampling, containment and eradication programmes and scaled up to provide more reliable regional and national estimates. Temperature, the key variable limiting the development of most insect species, may prove to be the simplest factor to interpolate, but progress worldwide is being made not only in interpolating rainfall and other climatic factors which influence the distribution of many crop pathogens, but also in mapping the edaphic and aquatic factors which may be critical for such diseases as sugar beet rhizomania and potato brown rot. GIS provide the means to analyse and integrate all these data and produce risk maps at a range of spatial scales. To increase the value of the risk maps, additional factors, e.g. land use and land ownership, can also be added. As decision support systems are developed for the principal plant health pests and diseases, GIS are likely to play a key role in displaying the predictions of the models for the end-user.

ACKNOWLEDGEMENTS

I am grateful to many CSL colleagues for their help in this work. Figure 1 is based upon Ordnance Survey 1:50,000 digital height data with the permission of The Controller of Her Majesty's Stationery Office © Crown Copyright.

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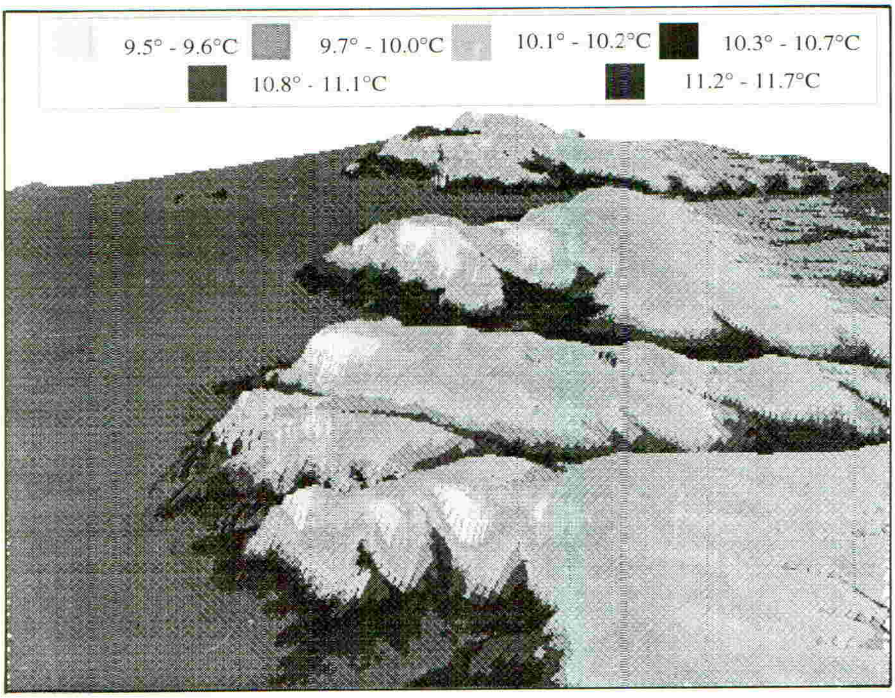

Figure 1: Mean 9 am April-June temperatures for a 20 x 20 km area of the Chilterns, England predicted using equations developed by White (1979) and displayed in a GIS.

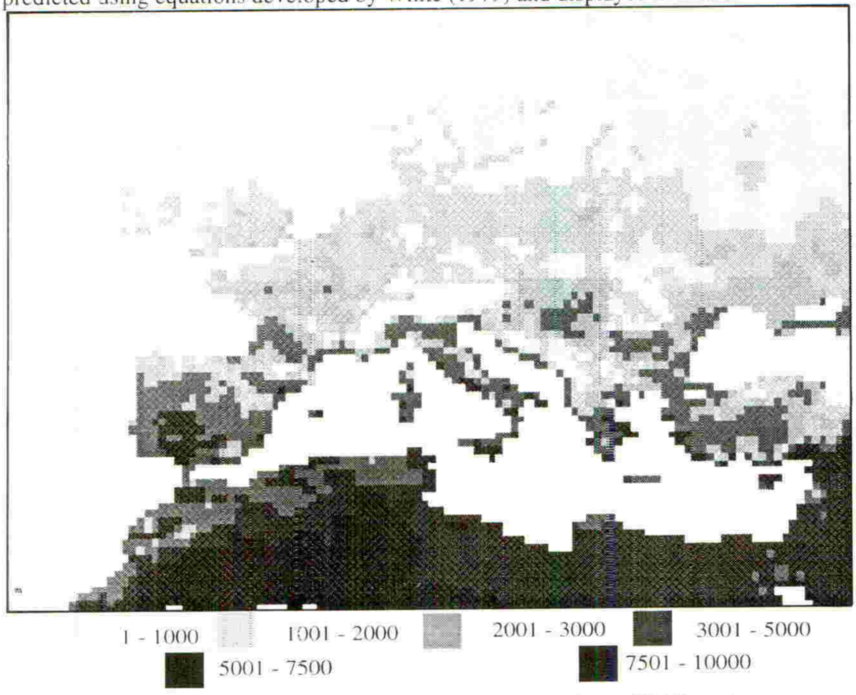

Figure 2: May - September accumulated temperature above 10°C based on monthly means obtained from the IIASA World Climate Database

PLANT HEALTH IN THE EUROPEAN SINGLE MARKET - A UK VIEW OF THE FIRST YEAR

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ABSTRACT

The challenge of the introduction of a Single Market in the EC necessitated complete reshaping of the entire plant quarantine legislation. Measures taken include the harmonisation of requirements at the outer border, listing and differential categorisation of quarantine organisms, introduction of the plant passport, increased information exchange and formation of an EC Inspectorate. Training and pre-registration of producers achieved early implementation of the measures in the UK. Although some pests have been intercepted (e.g. *Liriomyza huidobrensis* on *Primula; Bemisia tabaci* on *Viola* and others with penjing from China) and certain inconsistencies remain, considerable improvements in safeguarding the EC from alien pests have been made.

INTRODUCTION

At other sessions of this Conference there continues to be interest and awareness of the new European Community (EC) legislation implementing the Single Market as it affects the regulation of pesticides. In parallel with this there have been similar developments in plant quarantine legislation. This paper reviews, from a United Kingdom (UK) perspective, some aspects of the first year of implementation. It should be noted that although the legislation includes many forest plants and associated harmful organisms for which the implementation has been similar, this paper concentrates on agricultural and horticultural aspects.

Legislation for a "Single Market" and GATT developments

The EC plant health strategy for the Single Market sought to minimise restrictions on the free circulation of plants and plant products within the Community whilst at the same time preventing the introduction or spread of harmful organisms into areas where they are not established and where they would present a risk to plants planted or otherwise growing there (Anon., 1987).

In addition, the Uruguay round of the General Agreement on Tariffs and Trade (GATT) included a Sanitary and Phytosanitary (SPS) agreement designed to ensure that restrictions are applied only to the extent necessary to protect plant life or health, are based on scientific principles and are not maintained against available scientific evidence (Stanton, 1993; Hedley this volume).

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These two separate developments have required both a re-examination of the accepted principles which have been the foundation for international plant health since the introduction of the International Plant Protection Convention of 1951 (van der Graaf & Iken, 1993) and also the mechanisms by which plant health operates within the EC. The remainder of this paper discusses these challenges as part of the development and implementation of the "Single Market" for Plant health in the EC. Of necessity, this discussion takes the UK point of view, with the natural isolation of our island culture under challenge.

THE EC PLANT HEALTH REGIME

The first EC plant health Directive (Anon., 1977) harmonised trade between Member States (MS). These early regulations required that trade with non-EC countries must meet EC minimum standards, but more stringent national measures were permitted. The development of this legislation, and some of the subsequent plant health problems has been discussed by Baker & Pemberton, 1993 and Bartlett 1993a. To implement the EC Single Market however, substantial legislative changes were made between 1991 and 1993 as described by Vereecke (1993). The principle features of this new EC plant health legislation are:

- all harmful organisms presently considered of quarantine concern are listed by name;
- the world is divided into countries outside the EC (third countries) and the MS;
- from third countries the importation of some plants and plant products is completely prohibited and there are other listed commodities (plants or plant products) which require an IPPC model Phytosanitary Certificate (PC) on importation to the EC;
- for most controlled imports the entire EC has similar import requirements;
- within the EC all commodities considered to carry a high risk of introducing and spreading harmful organisms must be controlled when moved anywhere within or between MS;
- EC producers and certain traders of such listed commodities must be registered and subject to official inspection;
- listed commodities produced or traded within or between MS must be accompanied by a plant passport;
- listed commodities may be inspected and may require further restrictive measures;
- certain areas of the EC are designated as Protected Zones (PZ) because particular pests are not established and extra measures may apply to movement of certain commodities into these zones;
- there are no harmonised regulations for the export of plant commodities from the EC.

Pathways of risk

The significance of many of the features listed cannot be described here, although the problems some have raised during implementation will be considered later. However, the way risk is assessed deserves comment. The risk of establishment of a plant pest is different from the risk of its introduction. Accepting that pathways for introduction vary in the degree of risk they represent is in accord with the new GATT-SPS agreement. For example, there are lists of organisms whose introduction into, and whose spread within, all MS is banned. But for many of these organisms, some potential hosts are controlled, whilst for others there is no control and for still others there are no special requirements beyond simple inspection.

During negotiation it was necessary to assess the risks presented by all plants, plant products and other objects which might be controlled within the EC. As no agreed methodology for pathway risk analysis had been developed by the EC, considerable use was made of the specific quarantine recommendations formulated by the European and Mediterranean Plant Protection Organisation (EPPO). However, because the EPPO area is environmentally more diverse than that of the EC, some Single Market legislation differs from the EPPO recommendations.

Generally, the risk of spreading new harmful organisms is considered highest with commodities originating outside the EC. These require, as a minimum, a PC to enter the Community. All plants for planting, as well as some fruit, cut flowers and seeds are included. Plants for use in aquaria, most seeds, some other fruit and all vegetable produce (but not potatoes) are excluded.

Commodities originating within the EC which require control must be accompanied by a plant passport. As the degree of risk from pathways was considered to be variable, the need for passporting was also considered to vary. A limited range of commodities require passports whenever they are moved. Many more only require a passport when moved to persons professionally engaged in plant production. In effect, these require passporting when being traded to professional growers, or when sold wholesale, but not when sold retail. A third category requires plant passports only when being moved into a PZ. There is a fourth category which is too easily overlooked; namely those plants and most produce that are not required to have a passport because the risk of carrying pests is considered minimal. It is important to emphasise that the novel part of the implementation of this concept is that the end-use of the commodity determines whether regulation by passport is required or not. Although this can be restrictive for some traders, it has freed many from any specific control beyond a duty of care to prevent movement of quarantine pests.

Although this categorisation was considered with care, compromises were required and some have proved to be too arbitrary. For example, during July 1994 the UK Plant Health and Seed Inspectors (PHSI) found *Liriomyza huidobrensis* on young *Primula* plants for propagation and *Bemisia tabaci* on *Viola* seedlings. Neither plant requires a plant passport at any stage, despite the UK having argued during negotiations that both are host to a variety of polyphagous pests and that *L. huidobrensis* had previously been found on both species in the UK (Bartlett, 1993b).

Categories of Pests existing within the EC

Protected Zone (PZ) pests

Some commodities require passports because they represent a risk to a PZ. This is the most obvious of the categories into which harmful organisms occurring in only part of EC may be placed. PZ organisms are recognised as being established in one or more parts of the Community but are not endemic or established elsewhere, despite favourable conditions for them to do so.

This concept is seen by some MS as an intolerable barrier within the Single Market. Due to the rigorous quarantine measures which have built upon the advantages of our island situation, the UK remains free of many harmful organisms and thus supports the concept. The problem lies in ensuring that the area remains free of these harmful organisms. For each of the UK non forestry PZ's there is a different way of attempting to maintain control. For *Leptinotarsa decemlineata*, for example, there are no special requirements whatsoever. Even freedom of seed and ware potatoes from the beetle is expected as a result of the general requirements imposed on these commodities throughout the Community. In contrast, many special requirements are required to prevent the further introduction of beet necrotic yellow vein virus (Ebbels, 1994). Between these two extremes, preventing the introduction of European strains of *Bemisia tabaci* is maintained by controls on the two principal hosts, poinsettia and *Begonia*. Control is needed to safeguard protected vegetable crops from both the pest and the many viruses that it can vector. Unfortunately, despite considerable pressure being brought to bear on the European propagators, introductions of *Bemisia tabaci* infested poinsettia are all too common. Additionally, the organism is being found during check inspections on an increasing range of vegetable produce and cut flowers originating within and outside the EC. Fortunately, neither over wintering of the pest in any UK glasshouse, nor spread to protected vegetable crops, has so far been discovered (Cheek & Macdonald 1993).

Pest area freedom and containment legislation

Although the legislation appears to highlight the PZ organisms, there are other categories into which organisms with limited distribution in the EC may be placed. Some which occur commonly have their own containment legislation as separate Directives, namely *Synchytrium endobioticum, Globodera pallida, G. rostochiensis* and *Clavibacter michiganensis* ssp. *sepedonicus*. The movement of yet other organisms is banned, despite being common in some areas of the EC. If any of these organisms are found to have spread to new areas this must be reported to the Commission. The three polyphagous *Liriomyza* spp which are present in the EC are good examples. Whilst *L. bryoniae* and *L. huidobrensis* are present but of restricted distribution in the UK, *L. trifolii* is not established (Bartlett, 1993b). This concept leads to problems when plants and produce are moved between infested and non-infested areas. When an organism is common in an area, it is not surprising that growers tolerate a slight infestation of plants or produce. However, this is unacceptable when the same commodities move to uninfested areas, even if no passport is required. Conceptually, the movement of the organism is always banned.

The new legislation requires eradication or containment measures to be taken when a quarantine harmful organism is found on an import, when commodities are moving within a MS or if there is an outbreak of the organism. EC Inspectors can investigate such incidents to ensure that suitable and adequate measures are being taken. The action taken by Belgium, Netherlands and UK to contain the further spread of *Pseudomonas solanacearum* has been investigated in this way. This has led to improved co-operation and harmonisation between the MS technical services involved with these unusual outbreaks.

IMPLEMENTING THE SINGLE MARKET

Phytosanitary certificates replaced by plant passports

An important consequence of the new legislation is that there is harmony of requirements for all commodities as they are received at the outer border of the EC. This new arrangement imposes considerable burdens on those MS who traditionally import a lot of plants and produce. They have to ensure that the imports meet all of the requirements of the EC, that accompanying documentation is correct and that consignments are inspected to ensure compliance. It is permitted to do some of this inspection post-entry at the place of destination. When these formalities are completed, a passport is issued to those commodities for which it is required whilst others circulate freely once landed.

The plant passport is perhaps the single most important and obvious change introduced by the Single Market. It is universally used when the relevant commodities are moved within the Community. Unlike the PC, the passport is not reserved for use when these commodities cross national boundaries; it is needed for all movement. This is a new concept for all MS. Perhaps, for UK residents, the name "passport" is misleading. In their normal lives, UK residents are not required to carry an identity card and use "people passports" only when leaving the UK.

Non - passporting of third country imports

Difficulties in harmonising controls on imports to the EC may be illustrated by the increased trade in miniature trees (penjing) from China and the resultant phytosanitary problems. These trees are only allowed access to the EC once they have met many different requirements. These involve control over a two year period prior to export and also many general provisions, such as that they should be clean, free from plant debris, flowers and fruits, have been grown in nurseries, and have been inspected and found free of pests and diseases. Another provision is that their growing medium has to be sterile at planting. After planting they either have to be treated to ensure freedom from harmful organisms or within two weeks prior to despatch the plants must be shaken free from the growing medium leaving the minimum amount necessary to sustain vitality during transport. In addition deciduous species must be dormant. However, many of the genera commonly grown as penjing do not require a plant passport once landed in the EC. The UK experience (shared with Italy at least) has been that these plants have both foliar and soil-borne pests present, which proves that the special measures are not being taken. Examples include: the mealybug *Rhizoecus hibisci* and another possibly undescribed *Rhizoecus* spp; an undescribed *Aceria* mite; a variety of nematodes including *Helicotylenchus dihystera, Paratrichodorus porosus, Tylenchorhynchus leviterminalis, Xiphinema* spp.; and a bacterium *Pseudomonas syringae* pv. unknown.

In both Italy and the UK, action has been taken to sterilise those plants imported directly from China. But random check inspections have revealed that many other penjing entering the EC and being cleared by other MS also have the same live pests present. There would appear to be a difficulty in implementing the legislation, both in China and in the EC, especially in interpreting the growing medium requirements. Also there may be doubts whether some plants are deciduous or not. These requirements, like many others in the Directive, are subjective and harmonisation of implementation will take time.

Registered premises and "person responsible"

The issuing of plant passports for every consignment of listed commodities moving within the Community would have placed an impossible burden on official plant health services. Therefore it was agreed that importers or producers must be registered and would be able to issue their own passports. The official services have an important supervisory role. Premises must be inspected regularly to ensure either they are free from quarantine harmful organisms, or that proper safeguards are in place to prevent their spread. These include the maintenance of records, carrying out regular inspections and a requirement to nominate a "person responsible" technically experienced in plant production to liaise with the official authorities. In the UK, this introduced many concepts which were new to growers.

The "person responsible" was seen as the key to the successful introduction of these measures. They would need information and training. Therefore PHSI trained groups of these "responsible persons" who also became recipients of both a newly introduced information series, the *Plant Health Newsletter* and also of *Quarantine Information Cards*. Each card illustrates and describes one or a few EC listed organisms and, in the fullness of time, it is planned that many of the listed organisms will be covered. The *Plant Health Newsletter* describes facets of the new regime as and when necessary. The distribution of these also highlighted another benefit of registration. With addresses being held on a database, growers of particular types of plants can be targeted with information which is of relevance to them. This facility had never previously been available to the plant health service.

Plant passports

Like a PC, a plant passport provides a way of signalling that the plant health checks have been carried out on a commodity prior to movement. Standardised particulars have been agreed for these passports which, unlike a PC, has to have part of the information attached to the plants, packaging or transporting vehicle (Anon., 1993a). The UK was instrumental in ensuring that whilst the format of a passport should be standardised, the appearance should not. This has had the beneficial effect that registered producers and importers have been able to adapt the style to comply with their own printing and labelling equipment. The UK system benefits from being less costly than alternative methods. It also meant that passports began to appear on UK plants and produce immediately the legislation became effective, at the beginning of June 1993 (Anon., 1993b).

In the UK, registration began as an optional exercise, well in advance of the introduction of the new legislation. Co-operation from the trade was excellent, with almost universal acceptance. The early start permitted some of the problems of the new scheme to be recognised and addressed before the new arrangements became a statutory requirement. This was not the case in many other MS, some of whom continued to issue PCs for commodities moving to other MS.

Trace back

In developing the legislation there was also some disagreement about those plants which should be required to carry a passport down to the retail level. Some argue that where necessary, every individual tree or tray of plants should be accompanied by a passport. The main purpose of a passport is, when a problem occurs, to be able to trace the source of the plants. This ability to trace back to source is critical because the quarantine controls are production controls. The UK has insisted that, if a batch of propagation material is found to be contaminated at one recipient's premises, then similar material must be traced and the supplier must provide lists of other customers who may have received plants from the same producer.

Some MS have been reluctant to provide such lists. Fortunately, when the UK has approached the supplier direct, customer lists have been produced.

Trace back is further complicated when plants pass through several intermediaries. This is a normal consequence of trade but a requirement to issue replacement passports retaining the registration number of the original producer has not been popular. The UK has permitted alternative arrangements, so long as the intermediary can prove that a written record of the origin is retained and available for PHSI inspection and use.

Charging for plant health

In the UK it is customary to charge for inspections needed for issuing PCs, and this is now extended to those required to support registration. However, no charge is raised for registration itself. Charging remains controversial. Each MS has a different opinion about whether charges should be raised for plant health and, if so, how this should be done. A common approach across EC has yet to be realised. However, perhaps the best way to remove objections is by demonstrating to the trade that they have benefited from the new controls placed upon them.

EC plant health inspectorate

To improve harmonisation an EC Plant Health Inspectorate has been formed. The main aims and functions of the EC Inspectorate have been described by Gennatas (1993). With relatively few staff in place there has been a conflict of priorities. The need to investigate plant health problems and situations in third countries has conflicted with that for the development of a handbook of instructions (vade-mecum) for all plant health inspectors in the EC. This vade-mecum is progressing only slowly.

Another role of the EC Inspectorate is to co-ordinate the reporting of interceptions made by MS on commodities from both outside and within the EC. The computer network which is essential for this complex arrangement is not yet in place. Further, there is a reluctance to communicate until the identification of a pest is completely confirmed. Although it is understandable that passing on incomplete or incorrect information is considered unprofessional, the speed of communicating new findings is important.

Introduction and retention of alien organisms, soil and plants

The UK has long recognised the importance for research and other purposes of a procedure to permit the introduction and retention of alien organisms, soil and plants which would otherwise be prohibited. High risks can be involved (*e.g.* when an organism is cultured) and a system has been developed which strictly licenses the conditions for such activities. The changes to EC legislation needed to permit these activities to continue are being developed.

CONCLUSIONS

The introduction of the EC Single Market has required almost total revision of plant health legislation by substituting safeguards and executive arrangements which are harmonised throughout the EC. This regime was negotiated under great pressure and to a tight timetable. Although inconsistencies and difficulties remain, considerable improvements have been made in increasing the consistency of safeguards for the EC area from alien pests.

ACKNOWLEDGEMENTS

I would like to thank my colleagues D. L. Ebbels, S. A. Hill and A. W. Pemberton for their useful comments on this manuscript.

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ASSESSING THE POTENTIAL USE OF BIOLOGICAL CONTROL AGENTS IN THE UK AGAINST PLANT PESTS OF QUARANTINE CONCERN

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ABSTRACT

Statutory controls of quarantine pests have traditionally relied largely on chemical measures and have not been perceived as being compatible with biological control techniques. However, importation and augmentation (inundation) techniques offer potential in this area; with inundative measures are already used in eradication and containment programmes against *Bemisia tabaci, Liriomyza huidobrensis* and *Opogona sacchari.* Environmental manipulation techniques to favour naturally occurring agents are suitable for protected crops for which also agents with broad spectrum activity have considerable potential as biological pesticides for plant health purposes.

INTRODUCTION

Biological control has been defined as "the action of parasites, predators and pathogens in maintaining another organism's density at a lower average than would occur in their absence" (Debach, 1964). It is a term that is often extended to include a wide range of non-chemical control methods such as host resistance, cultural, semiochemical, or genetic modification techniques such as sterile male release, and also encompasses the biological control of diseases and weeds in addition to control of invertebrates. However, the scope of this paper will be limited to the potential role that parasites, predators and pathogens can play within statutory controls of invertebrate crop pests not already established in the United Kingdom.

THE NATURE OF QUARANTINE PESTS

The pest status of an organism causing damage to crops varies according to where it occurs. It may not be a pest in its natural habitat, but its status may change as a result of ecological disturbance or by transport to a new environment. With increasing intercontinental trade and travel, scope for the introduction and spread of potential pest species is continuing to grow (Baker & Pemberton, 1993). Many agronomically important crop pests have, with human assistance, overcome the restrictions of local geographic boundaries and have thus gained far wider dispersal capabilities. Regulatory controls and quarantine practices are an important means of minimising the spread of such pests. Quarantine organisms often share similar characteristics which contribute to their high pest status. They are usually :-

* Polyphagous, attacking a wide range of economically important host plants;

* Difficult to control, having developed resistance to conventional pesticides;

* Released from natural control systems and capable of explosive development;

* Suited to protected glasshouse environments in the UK and northern Europe if introduced from warmer climates;

* Genetically 'plastic', allowing rapid adaptation to new environments.;

* Transported in close association with host plant material;

* Difficult to detect;

STATUTORY CONTROL OF QUARANTINE PESTS

International plant health (quarantine) legislation aims to prevent the dispersal of harmful organisms to new regions of the world where they could be damaging. In the UK, the Plant Health (Great Britain) Order 1993 is based on quarantine legislation within the Single Market trading regime of the European Community (Bartlett, this volume). To facilitate trade from regions where a pest is known to occur, or trade in commodities known to have a high risk of carrying quarantine organisms, a number of internationally accepted in-transit treatments have been developed. Such treatments are required to give complete, rapid and reliable kill and include hot water treatment, irradiation, heat and cold treatment or fumigation (Paull & Armstrong, 1994). Treatments for planting material rely heavily on fumigation techniques, particularly those using methyl bromide (Macdonald & Chakrabarti, 1993). However, the long term use of methyl bromide is in question due to environmental concerns. There is thus a need not only to search for alternative fumigants in the short term but also to look at the whole philosophy of such treatments and whether reliance on a single pre-transit treatment should continue in future.

Whilst legislative controls and pre-transit quarantine treatments aim to exclude potentially harmful pest species from colonising new areas, there will inevitably be a small number that are introduced and for which containment and eradication measures may be required. The use of biological control methods in statutory pest eradication and containment programmes has been viewed as inappropriate, with the concept of eradication incompatible with that of biological control. However, their use within statutory control programmes is not to be excluded, but rather, depends on the circumstances of each introduction. Where the damage potential and associated risk from pest introductions require a rapid response, and if effective chemical controls are available, it is unlikely that there would be justification for a less well tested and less reliable alternative that will require a greater management input. Conversely, where a new pest is introduced into a contained environment and an extended period of treatment is permitted, there is considerable scope for biological controls to play a part.

BIOLOGICAL CONTROL STRATEGIES

Although biological pest control methods have been long established, the development of synthetic insecticides in the 1940s revolutionised pest control practices. Insecticides were cheap, highly effective and easy to use, giving rapid results and high mortality against a broad range of species. Agricultural production thus grew to rely heavily on their use and it was only much later, in the 1960's, that serious doubts were raised following the development of problems such as pesticide resistance, secondary pest resurgence and in particular, non-target effects in the wider environment. Attention then returned once more to biological control methods.

Biological control has been successful in a wide range of ecosystems: forests, protected, annual and perennial crops, temperate and tropical regions, within islands and across continents. A number of strategies have been adopted, including the importation of exotic species, conservation of naturally occurring beneficial species and augmentation methods.

Importation of exotics

Importation methods are the best known approach that has resulted in many renowned successes as well as famous failures. This 'classical' approach to biological control involves expeditions, searches and importations of beneficial organisms from the country of origin of the pest, followed by release programmes aiming at the successful and usually permanent establishment of the natural control agent in the new environment. This method can be successful, particularly in stable environments, but is less so in continually disrupted agro-ecosystems.

This approach appears to be the most appropriate response to an introduction of an alien 'pest' species, as an attempt at redressing an imbalance. However, there are a number of factors which need to be considered with regard to the release of non-indigenous organisms into the wild. In the UK, such releases are controlled by the Wildlife and Countryside Act (1981). Application for a licence to release any non-indigenous organism is made to the Department of the Environment (DoE). Information is required on the biology, geographic distribution of the organism, the conditions of release and the receiving environment and the potential environmental impact. This includes its potential for establishment, interaction, and competition with other species and information on monitoring and control procedures. The release of a highly specific parasitoid is thus likely to be viewed more sympathetically than an active, highly polyphagous predator which may be able to dominate the ecosystem into which it has been introduced. Wider consideration of the release by other organisations, including MAFF, takes place via the Advisory Committee on Releases to the Environment (ACRE). There is some debate over the interpretation and scope of releases into the wild under the terms of the Wildlife and Countryside Act. The extent to which releases into a "contained" environment (such as a glasshouse) could be exempt from such licensing controls is being debated and has important implications for plant health.

Conservation

Manipulation of the environment can be of benefit in conserving and encouraging naturally occurring biological control agents. Careful timing of sprays, the use of 'banker' plants to provide a continuous inoculum of predators or parasitoids and management of field boundaries are examples. Such measures can be particularly important in the control of indigenous pest species, where an existing range of natural controls are known to be locally established, but their effectiveness has been in some way affected by agricultural practices or other disruption of the agro-ecosystem. It is thus of limited importance for new non-indigenous pests as a major strategy.

Augmentation

Augmentation techniques involve the mass production and controlled release of biological control agents, resulting in usually temporary impact on the target environment. Such periodic releases can be **inoculative** or **inundative**.

Inoculative releases involve relatively small numbers of biological control agents, which are intended to propagate in the target environment so the progeny can effect control for several subsequent generations (Debach & Rosen, 1991).

Inundative releases are aimed at achieving immediate control by the organisms actually released, rather than their progeny and larger numbers are released (Debach & Rosen, 1991). Thus the immediate performance and prey mortality are of concern rather than the reproductive and dispersal characters. Inundative methods are those most commonly used for plant health purposes and for which there is clear potential for development, particularly in protected cropping systems. Microbial agents are also commonly used in this way. Microbial insecticides based on formulations of bacteria, protozoa, fungi and viruses are regulated by the Control of Pesticides Regulations (COPR) under the Food & Environment Protection Act (1985). These are thus subject to the same registration requirements as a pesticide, whereas other organisms such as arthropods and nematodes are not covered by COPR.

PRESENT UTILISATION OF INUNDATIVE METHODS IN PLANT HEALTH

Although chemical controls have traditionally been favoured for quarantine pests, there has been increasing use of inundative biological techniques in recent years, to avoid unnecessary disruption to routine biological pest management programmes, particularly in protected crops. Where a small number of individuals of a quarantine pest are introduced to an environment in which it poses a low risk, (for example, *Bemisia tabaci* on poinsettia cuttings,) a treatment programme is permitted which is aimed at being compatible with routine pest management techniques wherever possible. A survey of more than 200 poinsettia growers in 1993 indicated that over one third of growers used *Encarsia formosa* as part of routine Integrated Pest Management programmes against whitefly, and approximately one third of *B. tabaci* outbreak sites also used *E. formosa* (Cheek & Head, 1994). The eradication programme for *B. tabaci* utilises introductions of *E. formosa* in conjunction with selective insecticides and a thorough glasshouse sterilisation treatment at the end of the season. It is well documented that *E. formosa* is not as efficient for control of *B. tabaci* as it is for the indigenous glasshouse whitefly, *Trialeurodes vaporariorum*, for which it is commercially produced. To compensate for this, a high rate of introduction must be used (1 per plant compared to the routine rate of 1 per 3 plants). Establishment and multiplication within the crop is not expected, as the parasitoids are utilised as a biological insecticide.

Similarly, the leafminer parasitoids *Dacnusa sibirica* and *Diglyphus isiae* can be used against the quarantine leafminer species *Liriomyza huidobrensis* in specific circumstances where eradication itself is not an objective, but a containment policy is operated to prevent further spread of the pest. Leafminer parasitoids have been successfully used in the control of *L. huidobrensis* on tomatoes (Van der Linden, 1991). However, the majority of introductions of this quarantine pest into the UK have been associated with chrysanthemum cuttings for cut flower production. The ornamental sector, in contrast to edible crops, remains largely reliant on insecticide based pest control programmes, due to the high quality requirements and low damage thresholds. However, entomopathogenic nematodes have been used in an eradication programme against a recent introduction of *Opogona sacchari*, the banana moth, in a UK glasshouse. The immatures of this species tunnel within the plant stem of hosts such as *Yucca*. They are thus difficult to detect and are protected within plant tissue from insecticide applications. Production of *Yucca* requires warm glasshouse conditions and high humidity, providing conditions well suited for the activity of entomopathogenic nematodes. Three applications of *Steinernema feltiae* were made over a six week period, which, combined with light trapping and space treatments against adult moths, resulted in successful eradication.

Inundative use is also made of microbial pathogens such as *Verticillium lecanii*, which has been applied to poinsettia cuttings on rooting benches against *B. tabaci*. Successful fungal infection has not always occurred, possibly due to prior fungicide treatment. *Bacillus thuringiensis* has also been used in protected crops against non-indigenous Lepidopteran larvae, though with limited success against *Spodoptera littoralis* (P. W. Bartlett, pers. comm.). Formulations commercially available in the UK are limited to those specific against Lepidopteran larvae, though a far wider range of products have been developed world-wide, active against a range of insect groups (Entwistle *et al*., 1993). There is, at present, little commercial justification for registration of further products in the UK, compared to tropical and sub-tropical regions where crop losses from invertebrate attack are more serious. *B. thuringiensis* is, however, by far the most successful biological control agent world-wide, and the continuing application of genetic engineering techniques offers enormous potential for further development of this bacterium for use in pest management (Cannon, In Press).

The present use of biological control agents in plant health eradication and containment is thus confined to commercially available formulations developed for use against indigenous species from similar insect groups. A number of difficulties can be experienced with using such indigenous biological control agents, such as unknown activity against a newly introduced pest species, and specificity, particularly with parasitoids that have close and highly developed physiological and behavioural adaptations to their selected host. With inundative methods, however, immediate mortality rather than the potential for reproductive synchrony and subsequent establishment is of prime importance.

POTENTIAL FOR FUTURE DEVELOPMENT

For pests newly introduced into the UK, an assessment of the control measures available will include biological, chemical and other available physical or cultural measures. Whether biological control is an appropriate strategy will depend on the environment into which it is introduced, the life history and behaviour of the introduced pest and the control agent(s) available.

Protected Crops

The protected crop environment provides opportunity for a high level of environmental control and manipulation and so offers great scope for the development of biological pest management strategies (Hussey & Scopes, 1985). New pests introduced over recent decades, have been capable of causing considerable damage in the protected crop environment, such as *Frankliniella occidentalis, Liriomyza trifolii, L. huidobrensis* and *B. tabaci* (Bartlett, 1992) and there has been considerable progress in developing effective biological control systems for glasshouse conditions (Van Lenteren, 1993). The area of edible crops treated with non-registered biological control agents (parasitoids and predators) in 1991 was double that recorded in 1985 and is continuing to increase, particularly in tomato, cucumber and pepper crops (Thomas *et al.*, 1993). As a result, it is these protected vegetable crops that are at particular risk from newly introduced pests which may jeopardise the existing biological systems by a need for insecticide treatment.

Public amenity areas

There are particular problems associated with the application of insecticides to environments with public access, such as botanical gardens, interior landscape areas, etc. The amenity sector is rapidly expanding and is responsible for the import of a wide range of tropical and sub-tropical foliage plants, potential hosts to a range of non-indigenous quarantine pests such as *Thrips palmi*. In addition to health and safety concerns, sheer size and density of foliage of mature plants and trees severely limit the application of insecticides and this situation is better suited to control agents which can actively seek out the target pest.

Prophylactic treatments on high risk crops

Recent research has explored the potential for the use of entomopathogenic nematodes against non-indigenous leafminers such as *L. huidobrensis*. Control can be achieved in conditions of high humidity (E. C. Williams, pers. comm.) such as those encountered during the commercial rooting process of chrysanthemum cuttings (*Dendranthema sp.*), potentially providing a useful prophylactic treatment of imported plant material that is safe to the environment and to the operator, while avoiding unnecessary use of insecticides. Other biological control agents such as fungal pathogens (including *Verticillium lecanii)* also have unexploited potential in this area.

Contingency arrangements

Maintaining pesticides for use in the event of an outbreak of a non-indigenous pest such as *Leptinotarsa decemlineata,* the Colorado beetle, is becoming increasingly difficult. Increasing demands are being made under the Control of Pesticides Regulations, particularly for residue data, in support of each crop. With no Coleopteran pest of potatoes in the UK, there is no commercial justification for the approval of products for this use. New formulations of *Bacillus thuringiensis* have been developed with activity against Coleopteran larvae and are approved in other parts of northern Europe where this pest is widely established. This biopesticide (along with other insecticides) has potential to be a useful future constituent of an eradication programme against *L. decemlineata* in the UK. Similarly, a large number of quarantine pests, particularly of the Coleoptera, are of concern to the forestry sector and *B. thuringiensis* and other biopesticides also have potential in forestry systems against a wide range of invertebrates.

Nematodes

The control of non-indigenous phytophagous nematodes is of concern as there are few effective control measures available other than soil sterilisation methods. Although many organisms within the soil can exert significant natural control, a major difficulty is in achieving predictable control in a soil environment where many of the factors influencing parasitism and predation are unknown (Kerry, 1987). However, there is particular potential where areas to be treated are small or clearly defined, as may be the case with sporadic introductions of non-indigenous species mainly associated with a specific trade.

'Model' insects

In the majority of cases plant health usage of biological control agents involves the application of agents already available commercially in the UK. An important area of research is in determining the extent that existing biological control agents, can be used against introduced pests with similar life histories to those of established species. This provides a useful base from which to develop wider ranging control strategies across pest groups rather than tackling each new introduction on a case by case basis. This approach is particularly suited to the investigation of agents with a wide spectrum of activity. Microbial insecticides and entomopathogenic nematodes thus appear particularly promising.

Importing non-indigenous control agents

UK legislation on the release of non-indigenous species requires urgent clarification in order to assess more fully the potential for importing natural enemies for use against newly introduced pest species, particularly in contained environments. In the longer-term, statutory controls may no longer be justified if effective biological control systems can be developed. However, this would require a substantial commitment in political will and resources for this to be a realistic prospect.

Legislative developments

The concept of 'appropriate treatment' is central to regulatory controls, whether as a requirement for freedom from quarantine organisms, or as part of marketing or certification schemes to minimise the spread of 'quality' pests. Such treatments can incorporate biological and other non-chemical measures and it is essential for legislative controls to maintain such flexibility and not preclude non-chemical controls. The ultimate judgement on whether a treatment is 'appropriate' or not, is based on the results, which in most cases is total freedom from quarantine pests and virtually free from quality pests. With an increasing shift in quarantine policy in recent years towards crop certification and a more integral approach (Baker & Pemberton 1993), this is likely to enhance the need for further biological control measures in future.

CONCLUSIONS

Statutory controls need, wherever possible, to be compatible with the pest management strategies within the cropping system into which a new pest is introduced. If introduced into a system where biological control is predominant, it can seriously disrupt a sophisticated and highly managed programme operating against the established pest complexes. Whilst in many cases immediate eradication actions are likely to rely on chemical means (due to the absence of any known alternative), there are clear prospects for the development of biological control methods as effective and more appropriate alternatives. This is not to suggest that biological control can be considered as a direct replacement for chemical controls, nor that it is likely to be successful when used as the sole means of control. It is, however, an important tool that offers considerable potential for development and incorporation in plant health practice.

ACKNOWLEDGEMENTS

I am grateful for the contributions and comments made by colleagues at the Central Science Laboratory during the preparation of this paper and for the funding of Plant Health Division, MAFF.

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PLANT QUARANTINE TREATMENTS: ARE THERE ALTERNATIVES TO METHYL BROMIDE?

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ABSTRACT

The listing of the fumigant methyl bromide under the Montreal Protocol is causing concern to plant health services throughout the world. No other treatment matches methyl bromide fumigation for wide-ranging efficacy, reliability and speed of action. There are currently no other treatments for live plants, propagating material and some plant products such as cut flowers, that give the guaranteed levels of control required for quarantine purposes while being safe for the plants concerned. Whether the usage of methyl bromide will be restricted in the future remains uncertain as our knowledge of its possible role in ozone depletion is incomplete. However, with the prospect of restrictions being placed on the use of methyl bromide, it is vital that alternative treatments are developed. Even if this fumigant should remain available for plant quarantine uses in the long term, such alternatives would reduce our reliance on a single method of treatment. There seems to be little prospect of any single treatment being devised that could replace methyl bromide for all its uses but a number of recent developments show potential for use as plant quarantine treatments. These are discussed and the results of some recent investigations into the use of phosphine as a quarantine treatment for pests on poinsettias and chrysanthemum cuttings are presented.

INTRODUCTION

There is a large and increasing international trade in plants and plant products and as a consequence plant pests and diseases can be readily spread around the world. In the past few years a range of damaging plant pests and diseases have been introduced to the UK and some of these have become established (Bartlett, 1992). Effective quarantine treatments can help to prevent the movement of pests and diseases. However, there are very few treatments that can reliably achieve the extremely high levels of control required if quarantine measures are to be effective and economic. Such treatments must ensure that all target organisms receive a lethal dose and that the treatment is reliable without harming the commodity being treated. There are a number of treatments that meet these criteria in certain cases such as heat or cold treatments, radiation or fumigation; all major treatments are listed and discussed by Paull and Armstrong (1994).

For a range of products, especially live plants traded as either ornamentals or propagating material, the major, and in many cases the only quarantine treatment currently available for the control of insect pests, is fumigation with methyl bromide. In addition to this role in preventing the introduction of pests to new areas, the gas is used as a soil and space fumigant and can thus be important in eradicating outbreaks of both alien pests and diseases. It is its importance for treating live plants, however, that makes methyl bromide so vital to plant health, as trade in such commodities can provide a direct route for pests to move between the horticultural industries of different countries. Introductions of leafminers (*Liriomyza* spp.) (Bartlett, 1993, Cheek *et al.* 1993), tobacco whitefly (*Bemisia tabaci*) (Cheek & Macdonald, 1993), western flower thrips (*Frankliniella occidentalis*) (Baker *et al.*, 1993) as well as many other pests have been associated with plant propagating material. The role of methyl bromide in plant health is discussed more fully in Macdonald and Chakrabarti (1993).

However, the future availability of methyl bromide is now in question. Following concerns about the role that methyl bromide might play in stratospheric ozone depletion, the Montreal Protocol has begun to place limits on the production of methyl bromide. It is currently proposed to restrict production to the 1991 levels by 1995, although this aim will be reviewed towards the end of that year (Anon, 1992a). The European Community has gone slightly further in announcing a planned 25% cut in production by 1996 (Anon, 1993). The USA has announced its intention to ban use of the chemical completely by the end of 2001 and other countries may follow (Anon, 1992b).

The methyl bromide global budget

Whether methyl bromide emitted from fumigations does play a significant role in stratospheric ozone depletion has been the subject of much recent debate. The total atmospheric methyl bromide balance is a complex and dynamic equilibrium. Butler (1994) points out that the oceans are supersaturated with methyl bromide. Thus any reduction in anthropogenic emissions is likely to induce a corresponding flux of the gas from the oceans, so that the overall atmospheric load would be unchanged.

It was estimated that 66,000 tonnes of methyl bromide was produced world-wide in 1990, of which only a proportion was emitted into the atmosphere. However, gas released from fumigations forms only a small part of the overall atmospheric methyl bromide budget. Mano & Andreae (1994) gave a best estimate of global methyl bromide emissions from biomass burning at 30,000 tonnes per year. This is comparable with that emitted by the oceans and fumigation together or about 30% of the total atmospheric budget. Methyl bromide emissions in exhausts from vehicles using petrol that contains bromine compounds as lead scavengers is estimated at 4,800-12,000 tonnes per year (Baumann & Heumann, 1987).

About 80% of the world-wide use of methyl bromide as a fumigant is for the treatment of soil (Anon, 1992c). It will be possible to reduce this amount significantly (B. Chakrabarti, pers. comm.) and when the effect of methyl bromide emitted from fumigation on stratospheric ozone is considered, the adjusted emission from this source should be taken into account, as suggested by Ko *et al.* (1994). Of the 66,000 tonnes of methyl bromide produced, only 8,400 tonnes were used for commodity treatments and only a fraction of this will have been used for quarantine treatments of live plants (Chakrabarti & Bell, 1993).

Economic benefits

The economic benefit of these treatments is difficult to assess. UK Plant Health policy requires that treatments be applied before import, thus it is nearly impossible for the authorities to know which goods have been treated. Even when treatments are carried out following import, the requirements are only for "suitable treatments" to be used, so no official records are kept of which treatments have been applied. In many if not most cases, however, they are likely to involve methyl bromide fumigation. Some idea of the potential economic benefit can be gained from the records of one UK grower who uses 30-35 kg of methyl bromide to treat £1.5 million worth of chrysanthemum cuttings every year (M. Plummer, pers. comm.). The final value of these as cut flowers will be much greater as would be the cost, both economically (Powell, 1979) and also probably environmentally, of controlling pests such as the American serpentine leafminer (*Liriomyza trifolii*) that have been successfully prevented from entering the UK by use of this treatment, (Bartlett, 1992).

ALTERNATIVE PLANT QUARANTINE TREATMENTS

The Central Science Laboratory has been involved in the development of plant quarantine treatments for many years (e.g. Powell & Gostick, 1971; Macdonald, 1993). Because of the potentially serious commercial consequences which would result if restrictions were placed on the use of methyl bromide for quarantine purposes, we have been looking at possible alternative treatments. Macdonald and Chakrabarti (1993) discussed a range of alternative treatments that might have a role in plant health. However, this paper concentrates on suitable treatments for live plants. The ideal replacement for methyl bromide would be another fumigant, as this could be introduced without the industry having to invest in expensive new facilities. The only other true fumigant available for use in the UK is phosphine. This has previously been used largely for the treatment of bulk commodities such as grain. Phosphine is a slow acting toxin, requiring treatments of up to 3 weeks to kill some organisms. Treatments of this length would be unsuitable for use with anything but dormant plants. Phosphine is also produced from solid formulations, many of which produce ammonia which is phytotoxic. Because of the time taken for the gas to be evolved, accurate control of gas concentrations is difficult. Most workers have therefore considered phosphine to be unsuitable for the control of pests on live plants. However, recent work, described below, suggests that this assumption may not be valid.

Hydrogen cyanide has been used in the past for treating dormant nursery stock which is sufficiently dry, but can only be used for some growing plants if they can be washed with water immediately after treatment to prevent burns from hydrocyanic acid (Bond, 1984). One other fumigant that may become available in the future is carbonyl sulphide. This has recently been patented world-wide for use in stored products with 100% kill of adult and larval insects being achieved in 6 hours (C.S.I.R.O., 1993).

The range of non-fumigation treatments is extremely limited. Cold storage may be suitable for some pests, particularly fruit flies (Armstrong, 1994) and further work may develop cold treatments for other species. Controlled or modified atmospheres have been shown to be effective against a range of pests. However, long treatment durations are generally required which are likely to rule them out for use on growing plants. Some adverse effects of these treatments have also been recorded on fruit (Hallman, 1994). Better use of conventional chemical or biological control techniques may provide an alternative. Work at the Silsoe Research Institute has developed a prototype apparatus for treating unrooted plant cuttings by tumbling them through a concentrated pesticide mist (Miller & Macdonald, 1994). Complete control of leafminers in tomato leaves has been achieved using conventional pesticides and some control was also achieved using entomopathogenic nematodes (P. Miller, pers. comm.). Further development work needs to be carried out but this system shows promise for use in some situations. Pesticide dips have also been shown to be effective in some cases. However, such treatments are labour intensive and pose a potential health risk to operators (Hara, 1994), although improved engineering could perhaps overcome these problems.

PHOSPHINE

Despite reservations about its potential, the results of a small pilot fumigation to test the efficacy of phosphine against horticultural pests were promising. Further fumigations were therefore carried out to investigate in more detail the toxicity of phosphine to two pests of horticultural importance and its phytotoxicity to two different species of plant. The pests chosen were the tomato leafminer (*Liriomyza bryoniae*), a close relative of several non-indigenous leafminers of plant health concern, and the tobacco whitefly *(Bemisia tabaci)*, a pest that has been repeatedly introduced to the UK (Cheek & Macdonald, in press). The plants chosen for the investigations were chrysanthemums, which are frequently fumigated to prevent the introduction of a range of pests such as *Liriomyza trifolii* (Bartlett, 1992), and poinsettias, which are the major source of introductions of *B. tabaci* and which have been shown to be damaged by fumigation with methyl bromide (Macdonald & Cheek, in press)

Materials and Methods

Fumigations were carried out in a 1.7 m^3 enamelled steel fumigation chamber maintained at 15°C. Phosphine gas was injected into the chamber as a 3% by weight mixture in carbon dioxide. The gas concentration was measured using gas chromatography and adjusted by the use of partial vacuum and dilution with air as required. Samples of *L. bryoniae* larvae in tomato leaves and scales and eggs of *B. tabaci* on poinsettia leaves, were fumigated for periods up to 48 hours. Single plants, approximately 20 cm tall of each of seven different varieties of poinsettias were fumigated for 32 hours with 0.97 $g.m^{-3}$ of phosphine. Batches of four different varieties of chrysanthemum cuttings were fumigated in the same way, two different varieties were also fumigated at 0.32 $g.m^{-3}$ for periods up to 72 hours (Table 1). Mortality and phytotoxicity were assessed at suitable periods after fumigation depending on the insect/plant tested.

Results

Table 2 shows the effect of fumigation against *Bemisia tabaci*, Table 3 the efficacy against *L. bryoniae*. Even at the lower concentration tested nearly 100% kill of *B. tabaci* scales was achieved within 16 hours. At the higher dose a similar level of kill was achieved in four hours, the shortest duration tested. Eggs of *B. tabaci* were more tolerant, with over 40% surviving for 8 hours. Substantial proportions of *L. bryoniae* larvae survived for up to 16 hours, though all were killed after 24 hours fumigation.

Table 1: Plant varieties tested for phytotoxicity

Plant	Variety	Dose (mg.l^{-1})	Duration of fumigation (h)
Chrysanthemum	Bright Yellow Boaldi	0.32	12-72
	White Reagan	0.32	12-72
	Amber Sheena	0.97	4-36
	Hurricane	0.97	4-36
	Yellow Fresco	0.97	4-36
	Delta	0.97	4-36
Poinsettia	Lilo	0.97	36
	Lilo Pink	0.97	36
	Diva Starlight	0.97	36
	Steffi	0.97	36
	PeterStar	0.97	36
	Regina	0.97	36
	Marbella	0.97	36

Table 2: Efficacy of fumigation with phosphine against *Bemisia tabaci*

Stage	Concentration of gas g.m^{-3}	Duration of fumigation (h)	Number tested	Percentage control (adjusted for control mortality)
Larvae	0.32	2	30	0
		4	54	73.6
		8	23	89.6
		16	136	99.8
		24	100	100
		48	110	100
		72	73	100
Larvae	0.97	4	56	98.9
		8	179	100
		16	145	100
		24	189	100
		32	93	100
Eggs	0.97	4	28	50
		8	7	57
		16	15	100
		24	17	100
		32	14	100

The phytotoxicity tests showed no significant damage to any of the chrysanthemum varieties tested under any of the fumigation conditions. Some stunting was observed, with plants set back by about a week compared to the controls, in cuttings kept at 15°C for 72 hours in both the treated and control samples. Poinsettias showed a small amount of leaf scorch within three to five days of treatment and for the varieties Diva Starlight, Regina and Steffi some leaf yellowing was apparent two weeks after treatment.

Table 3: Efficacy of fumigation with phosphine against *Liriomyza* larvae

Experiment	Duration of fumigation (hours)	Number of pupae produced
1	Control	22
1	4	33
1	8	36
1	16	11
1	24	0
1	32	0
2	Control	97
2	8	126
2	16	27

DISCUSSION

The results for *B. tabaci,* in which all stages tested were killed within 16 hours at the higher concentration, suggest that phosphine fumigation may be suitable as a quarantine treatment for this pest. Although some phytotoxicity was observed on poinsettias this was at doses well in excess of that giving 100% kill of the pest in these trials. Further work will be needed to verify the efficacy of this treatment, particularly for the eggs, which in many insects pass through a stage in which they are highly resistant to phosphine, and to determine the level of phytotoxic damage at lower doses. *L. bryoniae* appear to be more tolerant of the treatment, with 100% kill only being achieved after 24 hours. This is considerably longer than the 4 hours currently required using methyl bromide and is unlikely to be suitable for the industry. However, with further investigation using different fumigation conditions it may be possible to reduce this time. Higher gas concentrations than those tested may allow a further reduction in the duration of treatment. Fumigating at lower temperatures may reduce the decay of cuttings and make longer treatments more acceptable to the industry.

Phosphine appears to offer potential for replacing methyl bromide as a plant quarantine treatment in at least some cases. There may well be plant/pest combinations for which phosphine will not prove to be suitable. However, in other cases it may allow the development of quarantine treatments where methyl bromide fumigation is unsuitable, such as whitefly on poinsettia, where methyl bromide is phytotoxic. Further work is urgently needed on other possible alternatives to methyl bromide fumigation.

Carbonyl sulphide has only been tested for a very narrow range of applications and needs further investigation for plant health use. Other techniques also should not be neglected. The mist spraying techniques that have been under development at Silsoe have shown that conventional pesticides, and possibly also biological control agents, may be able to achieve the levels of kill demanded by quarantine treatments. In view of the possibility of further restrictions being placed on the use of methyl bromide, all possible alternative quarantine measures should be investigated as a matter of urgency. Even in the event of methyl bromide remaining available there are areas where it does not provide a suitable treatment and it is perhaps unwise to rely too heavily on any single treatment.

ACKNOWLEDGEMENTS

This work was funded by Plant Health Division of MAFF. *Bemisia tabaci* was held under MAFF licence numbers PHF 1526A/1036/44 and PHF 1526/804/113. We thank Swallowfield Horticultural Enterprises for the supply of chrysanthemum cuttings used in the second trial and Robert J. Mitchell and Amanda L. Clifton for technical assistance

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