Pesticide Resistance Management

A Biannual Newsletter of the Pesticide Research Center (PRC) in Cooperation with the Western Regional Communication Committee (WRCC-60)

Volume 1, No. 1 **January, 1989**

Editorial

This newsletter is funded through a grant from the New Initiative Fund of the Pesticide Research Center in conjunction with WRCC-60 (Western Regional Communication Committee on Pesticide Resistance). The Pesticide Research Center is an interdisciplinary center at Michigan State University with a mission of developing economically and environmentally sound pest management strategies for the future. WRCC-60 is a committee that was initiated in the western region of the U.S. in 1985. Today, WRCC-60 has representation across all regions of the U.S. with participants from Canada and other countries as well. The objective of this newsletter is to foster communication, research, and policy that will result in the amelioration of pesticide resistance problems.

WRCC-60 has met four times, 3 in conjunction with major society meetings (2 Entomology Society of America (ESA) and 1 American Chemical Society meeting (ASC)). We have arranged to meet during the 1989 American Phytopathological Society meeting (APS) August 20-24, in Richmond, Virginia. If you are interested in joining WRCC-60 and/or in receiving this newsletter please fill out the address form on the back of the newsletter.

WRCC-60 has ongoing communication with other organizations with resistance concerns including: USDA, Agriculture Research Services (ARS), Experiment Station Committee on Organization and Policy (ESCOP), Pyrethroid Efficacy Group (PEG: an industry organization) and the presidents special committee on insecticide resistance of Entomological Society of American (ESA). We have also endeavored to contact other national and international organizations interested in pesticide resistance. WRCC-60 has co-sponsored a workshop on resistance with ARS at the July 19, 1988 International Congress of Entomology in Vancouver, B.C. We have also co-sponsored a symposium at the American Chemical Society (ACS) September, 1988 meeting in Los Angeles. In addition, several cooperative research projects have been strengthened through WRCC-60 fostered communication and contacts.

This *Pesticide Resistance Newsletter* is composed of editorials, news and reviews, meetings and symposia announcements, WRCC-60 minutes, funding opportunities, professional opportunities, legislative highlights, resistance around the globe, abstracts from WRCC-60 members, Working Groups, reports and other regular features. This is the first newsletter and we have an international mailing list of approximately 800. You can help us by notifying your colleagues of WRCC-60's existence and purpose. In addition, parts of the newsletter could be adopted or incorporated into other forms of communications. We are also looking for your suggestions for input into the July edition of the *Pesticide Resistance-Newsletter.*

This *Newsletter* will attempt to provide a service in alerting its readers to new cases of resistance which arise in the field or laboratory through regional coordinators. Those submitting reports of new cases must do so with assurance and responsibility for the credibility and the significance of their data and observations. They must disclose fully the extent to which they have supporting data and confirmation of resistance. The editors reserves the right to deny publication of reports which are deemed unsupported or unconfirmed, or which appear to be based on procedures which are not scientifically sound.

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A Rationale for Broadening the Scope of WRCC-60

In the 1940's when agriculture was getting its first real taste of the power of synthetic insecticides, a few individuals like Smith waved a red flag, pointing to the potential of insects to adapt to these poisons. In the rush to embrace the power of chemotechnology, these warnings were for the most part ignored. WRCC-60 was created to deal with the problems of pesticide resistance only after the devastating worldwide effects of resistance were upon us. In some ways we are in the position of a clean-up operation. We had no input regarding the kinds of pest management tools developed by chemotechnology, and only recently have we had an impact on the way these tools are used.

Today , biotechnology is still in its infancy, but appears to have the potential of offering agricultural pest management tools that are as powerful, or perhaps more powerful, than the tools offered by chemotechnology. Many entomologists and plant pathologists have shied away from involving themselves in the development of these new tools. I have heard a number of rationales for this shyness, including the statement that "*I am not trained in this area. I don't understand all of this molecular genetics.*" But how many of us were trained as chemists? Has this lack of ability to synthesize pyrethroids dictated that we not be involved in how they are developed and used?

I would like to argue that it is now time for plant pathologists, weed scientists, and entomologists to take a long-range view of the impact that biotechnology may have on agriculture. If biotechnology comes even close to achieving the goals set for it, there is a need to assess strategies for using biotechnology that will lead to the greatest societal benefits.

If genetic engineering techniques succeed in producing microbes and plants with the capacity to kill 99% of a pest population, won't we be facing problems of pest adaption to these potentially useful tools? It is already known that insects can adapt to strains of pathogens, resistant plants, and biologically produced toxins. Transgenic tobacco and tomato plants are already available that can kill over 95% of *Heliothis virescens* larvae and 100% of *Manduca sexta* larvae. These plants contain an endotoxin from Bacillus thuringiensis that can be adapted to by a number of insects, including *H. virescens*. Other potent biopesticides are in the pipeline. Optimistic genetic engineers see the supply of toxins being as unlimited as did optomistic chemists in the 1940's.

Genetically engineered plants and microbes will differ from synthetic pesticides in many characteristics ranging from effects on natural enemies of pests to marketing considerations. For example, a farmer can buy a synthetic pesticide and put it on the shelf until scouting information dictates the need to use it. Seeds of transgenic plants must be purchased long before pest abundance can be forecast. This could lead to a move back to prophylactic pest control. With current transgenic plants that produce toxin in all tissues, all the time, selection for pest adaptation will be as strong when pest numbers are low as when they are high. Given that many of the internally produced toxins of transgenic plants will not kill natural enemies, there is rarely a need to kill 95% of an insect population with these toxins. Unfortunately, it is not too difficult to produce highly toxic plants and these have obvious appeal to farmers.

There are many strategies that can be used in developing transgenic plants that might slow down rates of pest adaptation. These include the use of mixtures of resistant and nonresistant plants, use of plants with combinations of toxins or toxins and deterrents, use of genes that are activated only in certain plant parts or only when a threshold of pest damage has occurred. These strategies differ in detail from strategies that are most suited for synthetic pesticides. All of these strategies are, however, rooted in basic concepts of evolutionary biology.

Members of WRCC-60 have experience with the intellectual and practical challenges involved in developing pesticide resistance management strategies. As such, we are in a strong position to start developing strategies for the development and use of products of biotechnology. I believe that today, while biotechnology is in its formative stages, we have the best chance of having an impact on its development. One could argue that resistant plants and genetically engineered microbes do not fall under the preview of a "pesticide" resistance management group, but I think that this would be a shallow argument. When a toxin produced by a plant kills 100% of a pest population, what is it to be called if not a pesticide.

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News/Reviews:

Acaricide Resistance Management Working Group:

At a recent meeting of research and industry personnel, it was proposed that a subgroup be formed under WRCC-60 (Resistance and Resistance Management to Pesticides in Pests and Beneficial Organisms). The group has a common interest in resistance to acaricides, with an emphasis in orchard crops. This group will serve as a forum for exchange of information and ideas on acaricide resistance management.

One of the key motivating factors behind the organization of this group was to involve the chemical industry, specifically those companies that have registered tree fruit acaricides, or compounds nearing registration. We all have a stake in the longevity of these products, and it is hoped that an atmosphere of cooperation can be fostered in order to help us to reach this common goal.

The first self-imposed charge of the ARM-WG will be to draft a set of guidelines for acaricide resistance management principles in orchard crops. Such a set of guidelines would serve as a valuable reference for persons wishing to incorporate resistance management into their IPM programs. We recognize that we still have much to learn about the theory and practice of resistance management but must have some operating principles to go on in the interim. The guidelines would be revised as new information is developed.

A rough draft of the proposal was sent to of the ARM-WG. A meeting to discuss the draft was held at the Imperial Hotel in January. For more information, please contact: Dr. Elizabeth H. Beers,Tree Fruit Research and Extension Center, 1100 N. Western Avenue, Wenatchee, WA 98801, (509) 663-8181

Dr. Elizabeth H. Beers
Tree Fruit Research & Extension Center
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GIFAP Educational Video on "The Paradox of Resistance" now available.

The FAO International Code of Conduct on the Distribution and use of pesticides states in Article 3.10: "*It is recognized that the development of resistance of pests to pesticides can be a major problem. Therefore, governments, industry, national institutions, international organizations and public sector groups should collaborate in developing strategies which will prolong the useful life of valuable pesticides and reduce the adverse effects of the development of resistance species.*"

GIFAP fully supports the principles expressed in this statement. As part of its commitment to fulfilling these objectives GIFAP has established two expert groups, the Fungicide and Insecticide Resistance Action Committees (FRAC and IRAC). A major function of FRAC and IRAC is to coordinate agrochemical industry efforts to prolong the effective life of management strategies, and consequently disseminating information and advice to all those involved with the use of these materials--from manufacturers, through distributors, advisory services and other government authorities and, most importantly, to the end-user. It is in this context that the companies involved in FRAC and IRAC have combined to produce an educational video entitled "*The Paradox of Resistance.*"

This 25 minute video set out to simply and clearly explain to a non-specialist audience exactly what resistance is, how and why it occurs and what can be done to avoid or minimize resistance risk, including basic advice on appropriate resistance management strategies. In addition to proposing the adoption of new strategies, the video also emphasizes the need to be realistic about what levels of control can and should be achieved with crop protection agents. If we aim for virtually total elimination in the short term of pests attacking crops then we risk the rapid loss of effective products--this is what the video describes and "*The Paradox of Resistance.*"

This GIFAP video will be available not only to the producers and users of crop protection products but will also be of considerable interest to a wider public including schools, training colleges, universities and other public sector interest groups. As the video concludes: "Resistance is an issue that no-one should ignore. In one way or another it can affect us".

Copies of the video are available (in English) in VHS PAL and VHS NTSC from the GIFAP Secretariat at the price of 1,200 Belgian Francs per copy. A written commentary is also available upon request. For more information contact: Christine Wilson, Technical Secretary,GIFAP, 79A Avenue Albert Lancaster, 1180 Brussels, BELGUIM, FAX Number, Country Code, plus 2-375-2793.

Christine Wilson
GIFAP
Belguim

Rutgers Centennial Symposium: Insecticide Resistance

On the occasional of the centennial of its existence as an academic department, the Rutgers Entomology Department decided to celebrate with a view to the future and hosted a symposium on insecticide resistance that covered both fundamental and practical aspects. Dave Soderlund, Geneva, lead off with a discussion of molecular work on the pyrethroid mode of action and stressed the importance and difficulty of isolating and characterizing the toxicologically relevant interaction. His talk was followed by a discussion by Roman Sawicki, Rothamsted, of practical resistance management of cotton pests around the world by rotating insecticide use and careful timing; his talk brought out the necessity of keeping a worldwide as well as a local perspective on crop protection practices. Thomas Sparks, Louisiana State University, addressed the role of behavior in resistance development and pointed out the importance of not dismissing defensive mechanisms that may be perceived as less important than target site insensitivity or detoxification. Alan Devonshire, Rothamsted talked about new molecular studies of resistance based on genetic changes of carboxylesterases and multiple forms of acethyl cholinesterase, defenses that can only be understood and evaluated by molecular biology and molecular genetics investigations. Steve Riley, DuPont, told the audience about the industry-initiated monitoring program for pyrethroid resistance and pointed out the interest industry has in optimizing the use of chemical insecticides. Rick Roush, Cornell, advocated the judicious use of theoretical models for designing resistance management strategies and stressed that certain parameters have more practical importance than others. R. L. Metcalf, University of Illinois, summed up with a historical review of the consequences of wholesale insecticide use and pointed out that there are many ways in which such use can improve so that resistance is delayed. There was a lively discussion which continued into the student-hosted evening barbecue featuring the products of New Jersey agriculture. The symposium will be published in the August issue of *Pesticide Science*.

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Resistance to Pesticides - An Industry Viewpoint: A transcript from the 1988 Joint Cornell/Industry Pesticide Resistance Conference

During the last decade there have been numerous conferences on resistance. I am sure that the most complete treatment of it is contained in the book "Pesticide Resistance- Strategies and Tactics for Management" published in 1986 by the National Research Councils Committee, chaired by Ed Glass.

I think one can fairly sum up the situation today by saying:

- that there have been many conferences, symposia and publications;
- that all of the above have recommended that more research be undertaken, the better to understand and define the nature and scope of resistance, as a vital first step to managing it;
- but that, finally, pathetically little practical action has ensued

Why is this? Does nobody believe the warnings, the cries for help? In round figures, I believe that the Federal and State Governments together spent some $2,000 million on agricultural research and development in 1986. Out of this, the USDA/ARS budget was over $500 million; but only $2 million was spent on research related to pesticide resistance problems.

Whatever the reason it is clear that no consensus has yet developed that pesticide resistance is a major problem.

Magnitude of the Problem

So, how big a problem is it, in financial terms? This was reviewed exhaustively by Georghiou in the NRC publication cited above. I have time only to present an overview; also, I wish to focus our thoughts on to the biggest problems.

I think, and I feel confident that many of you will agree, that the class of pesticides which presents the greatest resistance problem is insecticides. Resistance (decreased susceptibility) to rodenticides and herbicides does exist, and is locally troublesome, but on the macroscale pales into insignificance besides resistance to insecticides/acaricides. One estimate quoted by Georghiou put the extra cost of controlling insects and mites due to resistance, at $133 million in the USA in 1979/80. There are many factors to consider, and I do not know how to confirm or challenge that figure; so perhaps we can accept it as a working hypothesis. World-wide, of course, we are talking about much more than money, for instance the millions of lives lost to malaria due to resistance to insecticides.

Fungicide resistance is real, and widespread, but my personal feeling is that fungicide resistance is less of a problem today than insecticide resistance. This is due to a number of factors, including probably

- the continued effectiveness of sulphur and copper-compounds, and of dithiocarbamates;
- the relative ease and success of breeding crops for resistance or reduced susceptibility to diseases, as compared to insect pests;*

(*Maybe because plant breeders have concentrated on disease rather than insect resistance? But there can be problems - a disease resistant celery which caused dermatitis, and a blight-resistant potato which was poisonous to man, for example.)

- the greater usefulness of traditional practices such as crop rotation, in avoiding the build-up of diseases;
- the fact that fungal pathogens tend to have fewer generations per year than many of the insects which have developed resistance most rapidly.

Insecticide Resistance:

What, then, are the parameters of the problem of insecticide resistance? Expert opinion seems to agree that:

- it is a real problem of intensive crop-growing, both in the Western world and in some less-developed countries (e.g. Malaysia, Thailand);
- it is a big problem, costing hundreds of millions of dollars in the USA, and maybe up to a billion dollars world-wide;
- it is an inevitable process, resulting from selection pressures, however caused;
- it is an increasing problem: in 1984, seventeen species were known to show multiple resistance to all five of the main classes of insecticide, including:
  - public health pests such as house flies (*Musca domestica*) and mosquitos (*Anopheles* spp.)
  - agricultural pests such as Colorado potato beetle (*Leptinotarsa decemlineata*), diamondback moth (*Plutella xylostella*), cotton worms (*Heliothis* and *Spodoptera* spp.), white fly (*Bemisia tabaci*) and the virus vector, peach-potato aphid (*Myzus persicae*);
- it is a problem that will get even more serious, because some insecticides have been banned, and the trend is for fewer new products to enter the market due to the ever-increasing length and cost of the registration process.

Now, if the problem is so serious, why has not more progress been made towards solving or mitigating it?

Barriers to Solving the Problem:

It seems to me that solutions are possible, but that there are two classes of barriers which have so far hindered real progress. These are technical barriers, and social barriers.

Technical barriers include:

- lack of knowledge, particularly of the genetic basis of resistance, and of population dynamics. A good scientific understanding of the problem is essential before the best methods of delay the onset of resistance can be devised.
- lack of reliable, sensitive, rapid assay methods--today, resistance has often become widespread and well-established before we can be certain that it exists: we

need good predictive methods which can be used in the field;

- the paucity of target sites attacked by the three dominant classes of current insecticides (pyrethroids - nerve sodium channels; OP's and carbamates - acetylcholinesterase);
- the fact that non-chemical methods of combating pests, such as crop rotation, control of fertilizer regimes, use of predators, breeding of resistant crop varieties, are relatively ineffective or uneconomic against the critical insect pests.

Social barriers:

But human beings are usually pretty ingenious at overcoming technical barriers. Probably the more significant obstacles to progress are the Social barriers. These include such factors as:

- the tendency for Government, industry and academia to have each left it to the other to take the initiative, whereas, in reality, a combined effort is essential. Regrettably, Government has tended to regard the problem as an industry problem - as we have seen, the USDA has virtually ignored it. Even more regrettable, many agrochemical companies have viewed a competitor's resistance problems as their own opportunity - a sadly myopic view. The Universitites and State Experimental Stations have done what they can with the limited funds that they have been able to attract, but on their own they cannot solve the problem;
- given that cooperation is an essential prerequisite to progress, the U.S. antitrust laws are a real, or at least perceived, barrier to progress. The Department of Justice has noted that cooperation in an insecticide resistance management program could be legally structured, provided that there is a genuine need and that the joint activity is limited to achieve the necessary objectives - but they wish to be advised in advance, on a case by case basis, and this does not seem to me adequately to remove the barrier.
- the mobility of insect pests, which means that individual growers are powerless to manage insecticide resistance, and that regional efforts are necessary. In turn, this means that both experimental programs and IPM programs require the broad support (both intellectual and financial), of the growers in a region before there can be any hope of success:
- the unwillingness, in the USA, to submit to an increased regulation of the use of pesticides by way to prescriptions. In some countries, such as Japan, Australia and Denmark, the number of times that a material or a class of pesticide can be used in one season is limited voluntarily or by law, in order to prolong their useful and effective life. In the USA both the growers and the chemical industry see such a suggestion as an infringement of their freedom of choice, but surely today we can see the writing on the wall? We must go down this path, for the only alternative we can see is the much more rapid loss of the increasingly precious insecticides that are still available.

The Way Ahead:

So, you can see - if you share my views - that we face some fairly formidable problems in attempting to manage insecticide resistance. But I believe that all is not gloom and doom.

Firstly, I believe that the main obstacle lies in attitudes - the social barriers that I described above. To put it another way, "Where there's a will, there's a way". And I detect a growing awareness that the management of pesticide resistance demands a collaborative effort:

- the industry (GIFAP)-sponsored bodies, IRAC and FRAC, are gaining credibility, effectiveness, and commitment;*
- commodity organizations, such as the Cotton Council, are promoting regional IRM programs;
- States are implementing IPM schemes.

So, I think that we may well be at a point described so aptly by a fellow countryman of mine, one Bill Shakespeare:

"There is a tide in the affairs of men
Which, taken at the flood, leads on to fortune;
Omitted, all the voyage of their life
Is bound in shallows and in miseries.
On such a full sea are we now afloat,
And we must take the current when it serves,
Or lose our ventures."

(*cf. papers presented at 11th International congress of Plant Protection, Manila, Oct. 1987 (Pestic. Sci. 1988, 23, 149-198)

Dr.Brian M. Savory
Rhone-Poulenc Ag. Co.

Symposium on Pesticide Management

The Entomology and Zoology Association of Thailand, Sumitomo Chemical Co., Ltd., and T.J.C. Chemical Co., Ltd. held a Symposium on Pesticide Management. The symposium was held on Tuesday, November 22, 1988 at 1:30 p.m. at the Vibhavadi Ball Room, Central Plaza Hotel in Bangkok, Thailand. The objective of this symposium was to discuss the appropriate uses of pesticides in a variety of Asian production and health protection systems.

Update on PEG-US/University Pyrethroid Monitoring Program on *Heliothis virescens* in the U.S. Cotton Belt

As a result of observations of increased synthetic pyrethroid tolerance in *Heliothis virescens* in the U.S. cotton belt during 1985 & 1986, the U.S. companies involved with pyrethroids (E.I. Du Pont & Co., FMC Corporation, Hoechst-Roussel Agri.Vet, ICI Americas and

Mobay) formed an inter-company technical group (PEG-US). The major goals of this group during 1987 and 1988 have been to evaluate the resistance situation in the cotton belt through intensive monitoring, evaluate different monitoring techniques and to put forward a series of pyrethroid-use guidelines based on the information obtained from the monitoring programs. This program has been an unprecedented effort involving the cooperation of the companies listed above and a number of university and private investigators across the cotton belt.

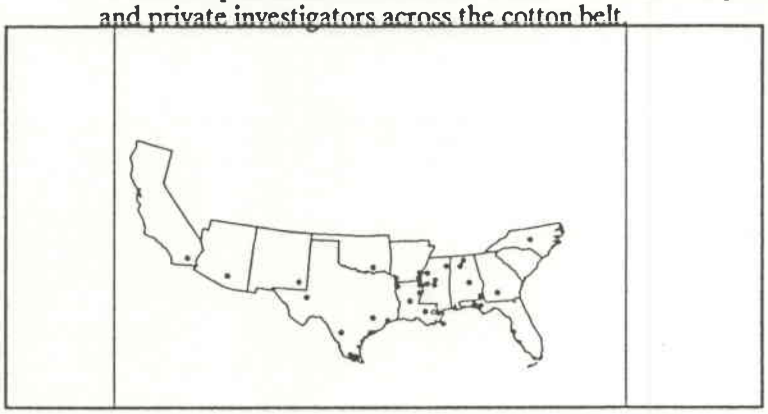

Figure 1 Areas at which adult H. virescens were collected and tested in 1988 with the Adult Vial Test.

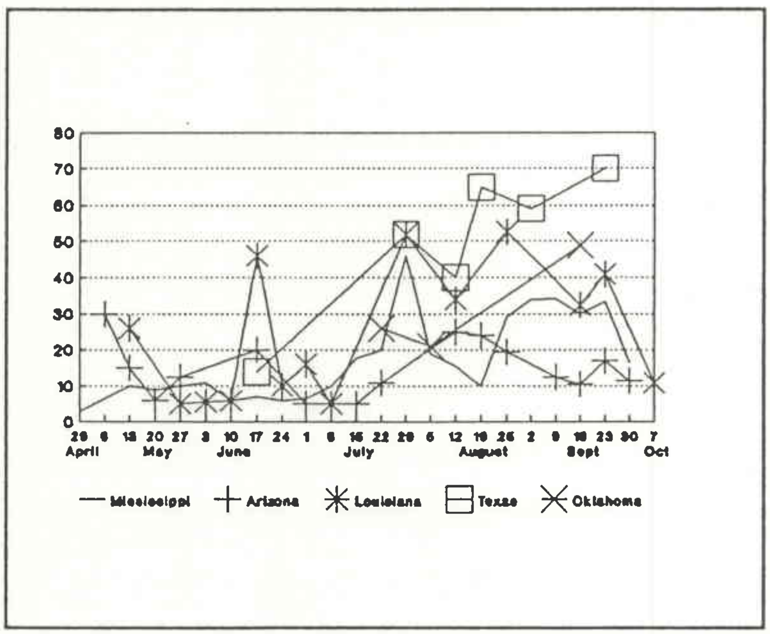

Figure 2 Survival of moths collected in AR, LA, MS, OK, and TX at the 10 ug/vial rate (cypermethrin) in the Adult Vial Test in 1988.

The field monitoring technique used extensively during 1987 and 1988 has been the Adult Vial Test (AVT) developed by Dr. F. W. Plapp of Texas A&M. More than 12,000 adults (245 tests) were tested during 1987 by PEG-US. In addition, university researchers conducted the AVT on approximately 25,000 adults (F. W. Plapp, pers. commun.). During 1988, PEG-US facilitated the expansion of the monitoring program by providing equipment (traps, pheromone & treated vials) and data forms to university researchers (Figure 1) A centralized data processing system was implemented, allowing the rapid analysis and distribution of results to cooperators across the belt. During 1988, more than 60,000 moths (589 tests) were tested.

Following the 1987 monitoring season, a list of guidelines emphasizing the judicious management of the pyrethroids were issued by PEG-US. In general, they supported the recommendations issued by Texas and the mid-south states (Arkansas, Louisiana, Mississippi). They were:

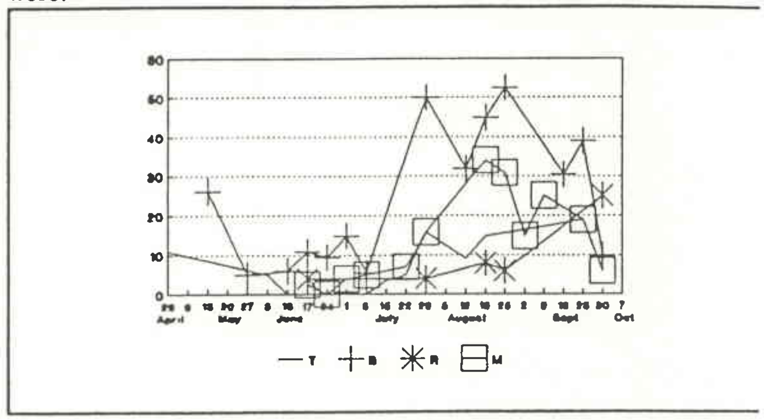

Figure 3 Survival data for adult H. virescens collected in four areas of LA and treated wity cypermethrin at the ug/vial rate in the adult Vial Test in 1988.

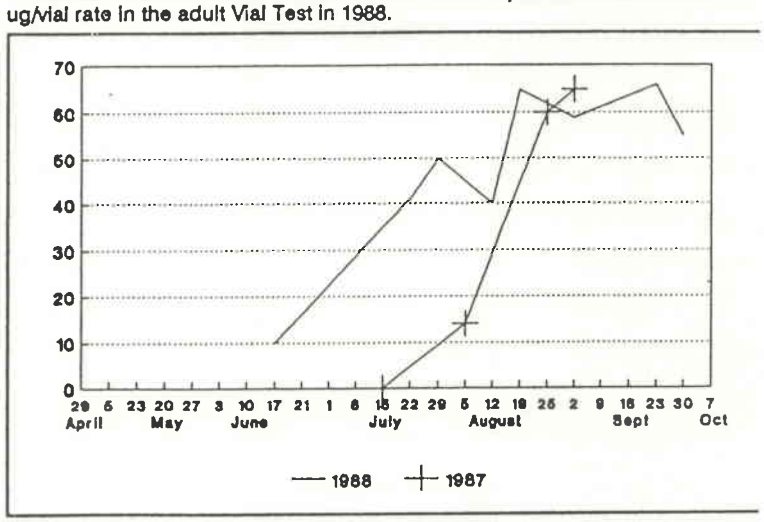

Figure 4 Survival data for adult H. virscens collected in the Brazos river valley of TX treated with cypermethrin at the 10 ug/vial rate in the Adult Vial Test.

- Do not rely on a single chemical class for tobacco budworm (TBW) control.
- Do not treat every generation of TBW with pyrethroids.
- Do not re-treat with pyrethroids following a field control failure.
- Do not rely solely on the use of mixtures or spray by-spray alternations of pyrethroids with non-pyrethroids.
- Ensure the timely application of pyrethroids on early instar larvae.
- Use pyrethroids at recommended rates and spray intervals.
- Timing and careful scouting are vital.

The general conclusions from the 1988 monitoring program were:

- Pyrethroid susceptibility levels as measured by the AVT indicate that good control of *H. virescens* by the pyrethroids can be expected during 1989. However, areas in Louisiana and Texas should be closely monitored.
- Susceptibility levels varied across the cotton belt and throughout the season with the lowest levels occurring later season in northwest Louisiana and the Brazos River Valley of Texas .

Although the AVT allows for the rapidly testing large sample sizes, its major drawback is that it only measures adult tolerances. This may not necessarily correlate directly with the performance of pyrethroids on larval populations in treated fields. We still need to better understand the relationship between monitoring bioassays and field control. This will be one of the major goals of PEG-US during 1989.

The current members of the PEG-US committee are Steve Riley & Ian Watkinson of Du Pont, Chuck Staetz of FMC, James Whitehead of Hoechst-Roussel, Harian Feeze and David Ross of ICI Americas, Don Simonet & Walt Mullins of Mobay, Geni Certain of Cotton Grower Magazine and Dr. Dan Clower.

Acknowledgement: The PEG-US technical committee would especially like to thank Drs. Jake Phillips, Jerry Graves, Bill Plapp and Martyn Collins and Marvin Wall for their support and cooperation.

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Meetings and Symposium:

IPM Symposium Set

The National IPM Symposium/Workshop will be held in Las Vegas, Nevada on April 25 to 28.

The theme is "*Application of Integrated Pest Management Programs.*" The symposium will include plenary sessions with speakers on new thrusts, post sessions, and regional IPM meetings. Workshops will focus on crops and on IPM thrusts.

Scientists involved in research and implementation of IPM can hear discussions of related new and developing technologies, discuss issues and concerns in workshops, present data in posters, demonstrate new computer software and confer with colleagues.

This symposium is sponsored by the National IPM Coordinating Committee. For more information write or call: Ed Glass, Department of Entomology, New York State Agriculture, Experiment Station, Geneva, NY 14456, (315) 787-2337

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Detection, Conservation and Management of Pesticide Resistance in Beneficial Arthropods: 1988 American Registry of Professional Entomologists

The 1988 American Registry of Professional Entomologists (ARPE) continuing education session was held in Louisville, KY in conjunction with the Entomological Society of America's annual meeting. This year's session was devoted to the "*Detection, Conservation and Management of Pesticide Resistance in Benefical Arthropods*" and was organized and moderated by Jim Cileck, Dept. Entomology, University of Kentucky. The ARPE session pointed out that pesticide resistance in benefical arthropods is not as apparent as it is for pests. However, management through conservation of resident resistant beneficals or intentional introduction into an integrated pest management system have the potential to enhance these programs, especially where pesticides form an integral part of the pest management scheme.

Evidence for pesticide resistance in benefical arthropods can be difficult to assess because of a variety of biological and operational reasons. With this in mind, detection methods which employ in vitro methods could prove to be quite valuable. Current methodologies involving detection of pesticide resistance using molecular technology was addressed by Dr. Tom Brown of Clemson University. The utilization of biochemical technology for in vitro detection of resistance was addressed by Dr. Biill Brogdon from the Centers for Disease Control, Division of Parasitic Diseases. Both speakers made reference to the application of these technologies to the detection of resistance in natural enemies even though the content of each presentation focused on pest resistance. Although detection is extremely important, equally important is the manipulation of resistant beneficals for field utilization. The genetic improvement of benefical arthropods resistant to pesticides was presented by Dr. Mark Whalon of Michigan State University. While augmentation of pesticide resistance in biological control agents through artificial selection and mutagensis was addressed by Dr. Jay Rosenheim from the University of Hawaii. Additionally, Dr. Bruce Tabashnik, also from the University of Hawaii, addressed the evolution and management of pesticide resistance in natural enemies.

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The First Asia-Pacific Conference of Entomology (APCE)

The first Asia-Pacific Conference of Entomology (APCE) is to be held November 8-13, 1989 in Chiengmai, Thailand. The APCE program objectives will be to provide a review of current knowledge of the major insect problems of The Asia-Pacific as well as the impact and management of insecticides in this region. New and significant findings and concepts will be particularly welcome.

Topics will include, but will not be limited to the following:

1. New Approach to Insecticide Management
2. Toxicology and Insecticide Resistance
3. Future Development of Insecticides
4. Systematics and Ecology of Insects
5. Insects of Medical & Veterinary Importance
6. Social Insects & Apiculture, Insecticides Safe for Bees
7. Insects of Agricultural & Forestry Importance
8. Pest Management
9. Biological Control

Chiengmai Orchid Hotel as well as hotels in Chiengmai will be designated for accommodation of all delegates and observers. The registration fee, if received before June 1, 1989 is $150 (U.S.) and if received after June 1, 1989 is $200 (U.S.). All cancellations must be received by telex or in writing. Cancellations received before October 1, 1989 will be subject to a service charge of U.S. $25. No refunds will be made after that date, but those unable to attend may send a substitute. **May 31, 1989 is the deadline for submission of abstracts.**

Mail to: Mr. Montri Rumakom, P. O. Box 1078
Bangkok 10903 Thailand

Symposium: Pest Control in Rice

Programme Structure

A three-day international symposium of invited speakers discussing the current and future methods of control of insect infestation, fungal and viral diseases and of weed competition in the major rice growing areas of the world. The symposium, organized by the Pesticides Group of the Society of Chemical Industry, is a continuation of the series on tropical crops and will be held at 15 belgrave Square on Tuesday-Thursday 5-7th June, 1990.

Session 1: Introduction

1. Methods of culture (wet, dry, seeded, transplanted, dapong)/varieties/geographical locations
2. Marketing: size relative to world crops, supply, consumption, import/export
3. Overview of problems in rice culture: insects, weeds, fungal/viral diseases, fertilizers, ecology

Session 2: Control of Insects

1. Insect varieties/location in crop canopy/nature of damage/disease vectors
2. Insecticide treatments: roots/paddy water/foliage
3. Biological control methods, integrated pest management systems

Session 3: Control of Disease

1. Fungal infections/sheath, leaf/growth stages
2. Fungicide treatments: seedlings/mature plants/wet, dry rice
3. Viral infections/treatments

Session 4: Control of Weeds

1. Weed varieties (wet, dry rice)/effects on crop/seedling, mature stages
2. Herbicide treatments/pre, post-emergence treatments

Session 5: Formulations, Application, Marketing

1. Types of formulations: solid, liquid/geographical location traditions/application methods/recent innovations
2. Marketing constraints/geographical location

Session 6: Future Trends

1. New chemical products
2. New varieties/resistance/biological control methods
3. Prospects for 1990/2000

Publication: Symposium monograph - available

Symposium Co-ordinators:
Dr. M. B. Green, Dr. M. G. Floyd, Dr. B. T. Grayson
Shell Research Ltd., Sittingbourne Research Centre
Sittingbourne, Kent ME9 8AG
United Kingdom

Reports:

Summary of the WRCC-60 Annual Meeting Held in Vancouver Canada on July 2, 1988.

Dr. Tom Brown of Clemson University chaired the meeting. Participants introduced themselves and passed out one-page research abstracts to update members on current research in pesticide resistance management. The application for renewal of the WRCC-60 as a coordinating committee was prepared and submitted in May 1988 by Tom Brown and Roy Fukuto. This petition included as goals for the WRCC-60; coordinating or administrative functions, scientific objectives, management objectives, and policy objectives. The chairman suggested that a future important goal of this group should be coordination of large center research proposals to obtain data correlating resistance to its real economic impact.

Subcommittee for Nomination of Candidates for Offices:

The committee proposed (and those in attendance voted to support) that the chair and secretary of WRCC-60 be elected for 2-year terms, the two officers to be elected on alternate years so as to provide overlap and continuity in leadership. In addition, only officially designated members of WRCC-60 are eligible to hold office. Finally, the offices will be elected by secret ballot with voting privileges extended to all who attend the annual meeting. Dr. Mark Whalon of Michigan State Uniersity was elected Chair and Dr. Beth Grafton-Cardwell of the University of California, Davis Secretary of the WRCC-60 for 1989.

Subcommittee for the New Meeting Site:

The group continues to express strong interest in holding the annual meeting in conjunction with phytopathology or weed society meetings in order to foster broad interdisciplinary interactions. The next meeting will be in conjunction with the American Phytopathology Society meeting, August 20-24, in Richmond Virginia.

Subcommittee for the Economic Impact of Resistance:

Optimization models are available for economic analysis of pesticide resistance. However, we do not have the biological and production data needed for the development of these models. We need to conduct more controlled field studies that include biological (yield) and production data (use of IPM, land quality, fertilizers, cultivation and harvest practices) in addition to the efficacy evaluations and resistance monitoring.

Subcommittee for Funding of Research:

It was suggested that the WRCC-60 solicit pre-proposals and provide submitters with funding leads and/or different research groups in contact with each other to prepare stronger joint proposals. Possible sources of funding include: the NSF Science and Technology Center, the USDA Pilot Test Program, USDA/NSF/NIH Competitive Grants, and Industry.

Dr. Ed Glass was involved in coordinating the WRCC-60 goals with the Experiment Station Committee on Policy (ESCOP). This committee now lists pesticide resistance as a priority and formed a committee on pesticide resistance management. The next effort of this committee will be to see if it can get some federal money put into pesticide resistance research.

Dr. Elizabeth Grafton-Cardwell
University of California
Davis, CA 95616

Resistance Around The Globe

Report on Herbicide Resistance Weeds

In the past, herbicide resistant weeds have been of local or minor economic importance, although they have served as very useful scientific tools to study herbicide modes of action, plant selectivity mechanisms, and biochemical or physiological processes. However, they are becoming much more serious due to rapidly developing biotypes resistant to chlorsulfuron and other new generation low-rate herbicides. Also, weeds resistant to atrazine and other triazine herbicides are spreading and have become serious in some areas. Mostly within recent years, weed biotypes resistant to at least 14 other classes or types of herbicides have been reported, as summarized in the following table. In addition, there has been a serious spread of weeds having multiple or cross-resistances to various classes of herbicides. Some of these weeds have the potential of having a major impact on crop production in the countries affected.

The need for research on the management of herbicide resistance is urgent. It is possible, that due to the large impact of herbicides on agriculture, herbicide resistant weeds will be a more serious problem within 5 to 10 years than pest resistance to insecticides and fungicides. This is almost certain to be the case if we depend too much on only a few of the new herbicides and discard our present and older herbicides. We will need all the tools we currently have, as well as those modern technology can provide, in order to manage our weed pests while further reducing or eliminating soil tillage, and conserve essential soil, water, and nutrients for future crop production. Herbicide resistant weeds need not interfere with present plans for biotechnology research aimed at developing her-

Distribution of Herbicide Resistant Weed Biotypes (as of January 1989)

Herbicides	# of R Species	# of States U.S.	# of Provinces Canada	# of other Countires
Atrazine & other triazines	55	31	4	18
Chlorsulfuron & other AHAS inhibitors	6	9	1	2
Paraquat & Diquat	11	0	0	0
Chlorotoluron & other substituted ureas	5	0	0	3
Diclofop methyl	4	1	0	3
2,4-D & phenoxys	3	0	1	2
Trifluralin & other dinitroanilines	2	4	1	0
Aminotriazole	2	0	0	2
Carbamates	2	0	0	1
Propanil	2	0	0	2
Uracils (e.g. bromacil)	2	0	0	1
Bromoxynil	1	0	0	1
Diuron	1	0	0	1
Mecoprop	1	0	0	1
MSMA & DSMA	1	2	0	0
Pyrazon	1	0	0	3
	91[1]	38[2]	6[2]	25[2]

[1] This is a column total. Even though some species are resistant to more than one class of herbicides, they are usually widely scattered or in different countries.

[2] These are not column totals, but indicate the total number of states, provinces and other countries where one or more resistant weeds have been reported.

bicide resistant crops, but the strategy and objectives must be altered to some extent. In particular, efforts should be aimed at developing major crops resistant to many herbicides, rather than one or two. This would provide greater flexibility in rotating or alternating herbicides to prevent resistant weeds from evolving and controlling those that do develop.

Dr. Homer M. LeBaron
CIBA-GEIGY Corporation
Greensboro, NC 27419

A FIELD SURVEY OF TRIAZINE-RESISTANT KOCHIA IN NEBRASKA

Triazine herbicide resistance in plants has now been identified in 43 species worldwide. Until recently, triazine resistance had not been documented in cropland of the central Great Plains. However, over the past five years, triazine resistant kochia populations have been reported in southwestern Nebraska. A comprehensive survey and rapid confirmation of resistance by field testing with a fluorometer was used in this study to document infestations of triazine resistant kochia in Nebraska.

A rapid and reliable method for investigating triazine resistance was developed using a plant productivity fluorometer. The procedure involves the detection of photosynthesis inhibition by measuring whole leaf fluorescence. A large difference (30-40 units) between the control and the atrazine soaked leaves indicated a susceptible plant, a small difference (0-20 units) indicated a resistant plant.

Triazine resistant kochia has spread throughout all of the southwest, south central, and parts of the Panhandle of Nebraska. The heaviest infestations appear to be in the southwest and south central counties. Small populations of triazine resistant kochia were found in central and southeastern parts of Nebraska. These populations were located in industrial sites. It is possible that triazine resistant kochia can be found on industrial sites throughout most of Nebraska.

Submitted by Dr. Dave Mortensen
Authors: Alan E. Haack, Beth A. Swisher, Gail A. Wicks, and Alex R. Martin,
Department of Agronomy
University of Nebraska
Lincoln, NE 68583

Funding Opportunities

WRCC-60 Subcommittee on the Funding of Research on Pesticide Resistance

Opportunities for Funding:

1. Plant Science Center - NSF/USDA/DOE: Historically oriented toward basic plant biochemistry-funding unlikely.
2. Science and Technology Center - NSF: Typically geared to Big Science-superconductivity, supercolliders, etc. This program will consider biology, especially basic molecular biology. Since its objective is to improve U.S. competitiveness, this program should be receptive to new technologies aimed to prevent or overcome resistance.
3. USDA Pilot Test Program: USDA three-year field program to implement new pest management technologies.
4. Competitive Grants - USDA/NSF/NIH: Historically, resistance proposals have not fared well.
5. Industry: Current state of consolidation in the industry may make funding of a center difficult at this time.

Functions of the WRCC in Securing Funding

WRCC cannot "sponsor" a proposal. A university of consortium of industry and academia must submit and assume responsibility for the proposal and subsequent funding.

WRCC can "coordinate" proposals and act as a clearinghouse of ideas for proposals, or funding leads--putting research teams in contact with each other, standardizing programs, etc.

Proposals

It is recommended that a WRCC subcommittee solicit one page "pre-proposals". The subcommittee would review these, provide the submittor with funding leads and/or put different research groups in contact with each other so that a stronger joint proposal could be organized. The subcommittee would also provide information on format rules and deadlines, and ensure that proposals be sent to the most appropriate agency.

Resolution for the Development of PRC Grant Proposals

The Experiment Station Committee on Policy (ESCOP) Subcommittee on Resistance has identified the Plant Research Center mechanism as the most appropriate means of funding resistance research. Although WRCC-60 is a regional communication committee, it does have considerable multi-regional representation and is the logical group to coordinate the development of PRC grant proposals.

We resolve that WRCC-60 identify a committee representing industry, university and USDA-ARS to review and coordinate proposals seeking PRC grants.

Dr. Thomas E. Anderson
BASF Corporation
Agriculture Research Center
P.O. Box 13528
Research Triangle Park, NC 27709-3528

Funding of Resistance Research by The Agrichemical Industry

The agrichemical industry has a large stake in research on resistance to agrichemicals. The cost of developing and registering products is enormous and growing rapidly. New materials are under increasingly careful scrutiny. It would certainly be short sighted to develop new products or support existing ones without considering the impact that resistance would have on efficacy, sales, and the useful life of the product.

In an effort to learn of industry's commitment to resistance reseach, a questionnaire was sent out to nine of the major agrichemical companies of the United States. This article reports the answers of each respondent at a recent conference on resistance to agrichemicals at Cornell University.

1. What ongoing or proposed research on resistance to agrichemicals is your company supporting? Why?

Dr. Brian Savory, Vice President, Research and Development, Rhone-Poulenc Agricultural Company: Rhone-Poulenc currently supports research comparing commercially available insecticides versus pyrethroid resistant insects. Pyrethroids are a dominant commercial group of insecticides in row crop, vegetable and fruit agriculture, and with increased use has some resistance problems. Our focus is to determine if our commercial insecticides offer growers an alternative to the resistance problems caused by pyrethroids.

Dr. Haney B. Camp, Vice President, Research and Development, Ciba Geigy, Inc.: We have been very active in funding or conducting in-house research to combat the resistance of pests, weeds, fungi and insects to our products. We also have active research studying modes of action to better understand how to combat resistance. Continuous programs are underway to monitor for resistance.

Dr. Walter Grimes, Vice President, Research and Development, Agricultural Chemicals Division, Mobay Corp.: Mobay is currently an active member of PEG-US which is involved in monitoring for pyrethroid resistance in Helothis on cotton. Through PEG we are also discussing resistance management strategy to prolong the useful life of pyrethroids in cotton. Additionally, Mobay is an active member of the U.S. branch of FRAC which is monitoring the baseline sensitivity of specific pathogens to sterol-inhibiting fungicides and promoting resistance management research.

Dr. David Ross, Research Biologist and PEG-US Representative, ICI Americas, Inc.: ICI Americas has two members on the Pyrethroid Efficacy Group-US (PEG-US). We participate in a program to monitor Heliothis resistance to pyrethroids using an adult vial test which is sponsored by PEG-US. In addition, ICI Americas has an extensive in-house program. We have for several years carried out a pyrethroid resistance monitoring program using a larval test. We plan to continue both in the future.

Dr. William Van Saun, Director, Biological Research Department, FMC Corp.: Pyrethroid resistance in Heliothis, 1) major contributor to PEG-US; 2) adult and larval monitoring programs - domestics Columbia, South America; 3) cross-resistance; and 4) mechanisms.

2. Are your active projects in this area conducted through grants in aid, contract cooperators, in-house or other?

Dr. D. Savory: We conduct this research primarily through university cooperator, grants-in-aid and in-house research.

Dr. H. B. Camp: Principally via university or in-house.

Dr. W. Grimes: We re presently funding outside projects as well as conducting basic research in-house to determine how our product line in concert with other products may fit into resistance management programs. Our in-house research is ocnducted both by Mobay in the U.S. and by Bayer AG in international programs.

Dr. David D. Ross: Predominantly in-house and with contract cooperators.

Dr. W. A. Van Saun: 1) in-house, 2) grants-in-aid

3. What problems/projects regarding resistance do you feel your company should/could support?

Dr. D. Savory: Through the ESCOP initiative on resistance, we are supporting the proposal to attract up to $25 million over 3 years to fund basic research on methods of combating resistance. ESCOP is targeting mainly increased USDA funding plus NSF, NIH, etc. I am also involved in trying to enlist industry support for a regional insecticide resistance research and extension program in the Northeast which would be implemented by Cornell University and the New York State extension service. Two basic objectives would be the field testing of alternative strategies for managing resistance and the search for more rapid and effective methods for determinig the existence of resistance problems in the field.

Dr. H. B. Camp: Educational programs to acquaint consumers with the nature of resistance and how to manage it.

Dr. W. Grimes: Our main emphasis at the present time deals with determining priorities for support of project which will give practical answers for resistance management. Mobay would be open to evaluating any research program aimed toward solving possible problems with resistance. This would include both basic research on modes of action, field monitoring programs and research on management strategies.

Dr. D. Ross: We will continue in the pyrethroid/cotton area. Other areas that we might consider supporting would be acaricide at B.t. resistance.

Dr. W. Van Saun: The most important area requiring further research is that of translating laboratory results to field situations and developing effective resistance management strategies.

4. What alternatives are available to fund resistance research on agrichemicals?

Dr. B. Savory: We support market driven resistance projects such as those suggested in question 1. Also, the PEG-US consortium research on well focused problems exists as an alternative to cooperator, grants-in-aid or more classical in-house research. The success of such industry organized programs need to have two components to be successful: 1) focus on well-defined problem or 2) focus on market IPM approach.

Dr. W. Grimes: Sources of funding for resistance research would be available through competitive grants, grower orgazizations and private companies. The important question is: What type of research is concerned? Very basic, theoretical research probably has the least opportunity for funding through the competitive grant system (USDA, EPA, etc.). Projects that deal with field control problems or possible future field control problesm would have opportunities for funding through grower organizaton for a particular crop. Also, if resistance to a particular chemistry group is suspected, then a group from the chemical industry, such as PEG, IRAC or FRAC could be approached for funding.

There are at present several different resistance groups forming which are all seeking funding for work of one type or another. We (Mobay) see much of this work to be rather unfocused as far as crop productivity is concerned. It is difficult for us to presently consider funding of projects which we feel are basically theoretical and do not pertain to production research which has the benefit of solving or minimizing possible resistance problems through strategies for resistance management.

Dr. R. Ross: Primarily through programs such as PEG and IRAC as well as direct support to uniersities.Thomas E. Anderson

Dr. Thomas E. Anderson
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Report on ESCOP Committee on Pesticide Resistance

The Experiment Station Committee on Policy (ESCOP) Subcommittee on Pesticide Resistance is still actively pursuing additional funding for research efforts to find ways and means of solving or ameliorating the resistance problem. It is an inter-agency committee representing the land-grant universities, USDA, NSF, NIH, EPA, AID, DOD, National Audubon Society, Boyce Thompson Institute and three pesticide manufacturers. It is chaired by Dr. Norman Scott, Research Director, College of Agriculture and Life Sciences, Cornell University.

Data has been gathered on the number of science years and the amount and sources of funding currently devoted to pesticide resistance research in industry, the land-grant universities and USDA/ARS. A brochure with color illustrations is in preparation to be used in contacting administrators, legislators and others concerning the need for additional support. We anticipate going to press early in 1989. Right now we need **publication quality** color transparencies of insects, mites, pathogens, weeds, rats and the injury they cause of species known to be resistant to pesticides. We are thinking of tobacco bud worm, 2-spotted mite, diamond back moth, Colorado potato beetle, German cockroach, bedbug, *Aedes* mosquito, house fly, horn fly, botrytus on grape, rat, and pigweed. I am not certain how many we can use but need a good collection to chose from.

We have decided for several reasons to expand the purview of the effort and brochure to include resistance to defense mechanisms in plants. Again we need slides of such examples as rust and Hessian fly on wheat, southern corn leaf blight, greenbug on wheat and planthoppers on rice. If there are others to consider, I should be glad to hear about them with good color transparencies. We can copy all materials sent and return the originals.

We shall appreciate your help in supplying appropriate slides for the brochure. **We need them soon.** Please send to: E. H. Glass, Department of Entomology, NYS Agricultural Experiment Station, Geneva, NY, 14456 (telephone 315-787-2337).

Dr. E. H. Glass
Barton University
Geneva, NY 14456-0462

Working Groups

Acaricide Resistance Management WorkingGroup: Management Strategies To Delay Resistance To Acaricides On Tree Fruits

Background

Mites have a long history of developing resistance to miticides. Many have lost effectiveness in only a few years of field use. The organotins (Plictran and Vendex) lasted much longer than most miticides, but resistance to these materials is now widespread in the U.S. and abroad. In countries where the new ovicides have been registered, resistance has been reported after only 2-3 seasons of use. Clearly, these materials are not exempt from the development of resistance.

With the registration of new miticides we have an opportunity to slow resistance development through appropriate management. Preserving the field life of miticides is more critical than in the past for several reasons: 1) The cost of registration is increasing every year because of more stringent EPA testing requirements, resulting in registration of fewer new materials; 2) tree fruits are considered a minor crop, and will have limited priority with manufacturers; 3) public concern over pesticide use in general is growing.

The understanding of the mechanisms for resistance, and ways of circumventing it, is still in its infancy. However, there are some research data that suggest resitance can be delayed. The following guidelines offer some general principles and practical suggestions.

General Principles

1. Rely on Biological control whenever possible.

Biological control can eliminate or substantially reduce the need for miticides. Conserve mite predators by using selective insecticides or miticides. Avoid applications of nonselective materials particularly when predators are vulnerable.

2. Use a miticide only when necessary.

Need can be determined by a series of leaf samples which provide the estimates of numbers of plant feeding mites and mite predators. Population estimates may then be coupled with established action thresholds to arrive at a decision. Avoid "calendar"-based miticide applications.

3. Use the lowest effective rate.

Dosage requirements may vary with the mite species, time of year and whether or not predators are present.

4. Alternate applications of miticides with different modes of action.

Guidelines For Specific Crops

Apples:

The dormant oil application is the key to European red mite ERM control. Instances of resistance to oil are known. This application will delay mite buildup and reduce need for conventional miticides. In the west, apple rust mite (ARM) is an important source of food for the western predatory mite (WPM), *Typhlodromus occidentalis*. ARM rarely occurs in numbers high enough to require control. An exception is on 'Golden Delicious' shortly before bloom when moderate numbers of ARM may cause fruit russeting. In the east, either predatory mites (*Amblyseius fallacis, Typhlodromus pyri*) or a predatory ladybug (*Stethorus punctum)* are the most important predators. To preserve predators, avoid the use of nonselective miticides, pyrethroids and Lannate. Use minimum rates of organophosphate insecticides necessary to control other pests.

1.	Delayed dormant:	oil + organophosphate for ERM eggs
2.	Early season:	East: use ovicide if mites exceed 7/leaf West: use ovicide if mites exceed 10/leaf and no predators are present
3.	Mid-season:	East: use adulticide if mites exceed ??/leaf West: use adulticide if mites exceed 30/leaf and predator number or distribution are inadequate.
4.	Late season:	East: avoid miticide use West: avoid miticide use

Pears:

Biological control is generally less successful on pears than on apples because 1) the lower injury threshold; 2) fruit injury is caused by the alternate food source (pear rust mite); 3) insecticides used against pear psylla eliminate predators. Use of "soft"programs for pear psylla offer the best hope for establishing integrated mite control in pear orchards.

1.	Delayed dormant:	oil for ERM eggs
2.	Early season:	West: use ovicide if mites exceed 1/leaf ('d'Anjou'); spray if mites exceed 2/leaf (other varieties)
3.	Mid-season:	West: use adulticide if mites exceed 2/leaf
4.	Late season:	avoid miticide use

Dr. Elizabeth Beers
Washington State University
Wenatchee, WA 98801

B.t. Working Group

The B.t. Management Working Group is a consortium of companies interested in research on B.t. resistance and in developing strategies to optimize the efficacy of B.t. products (microbials and plants). In anticipation that the working group will be raising a pool of funds to support a limited number of projects, we are now soliciting 2-3 page pre-proposals for future funding on the following research topics (in order of priority)

1) What is the potential for insects to develop resistance to B.t.?
   a) What is the likelihood of cross resistance developing to different B.t. endotoxins?
   b) Will selection to two or more endotoxins delay resistance development?

2) What is the cellular mechanism of resistance to B.t. (as related to the mechanism of action of B.t.)?

3) Development of a field monitoring program for detection of B.t. resistance.
   a) Baseline database of susceptibility to B.t. in field populations.
   b) Standardized lab/field assays for assessment of susceptibility and detection of resistance in insect population.
   c) Development and validation of predictive population dynamics models.

4) Development of strategies for optimizing efficacy of B.t. products such as:
   a) Multiple genes (B.t. or non-B.t.)
   b) Tissue/temporal specific expression
   c) Multilines
   d) Altering expression level
   e) Product rotation

Pests of primary interest:

Heliothis, Colorado potato beetle, European corn borer, Diamondback moth, Spruce budworm, Mosquitoes, Cabbage looper

Pre-Proposal Deadline: March 1st.

Pre-proposals will be evaluated and decision made by April 1. Those researchers whose pre-proposals are selected will be notified with a request for full proposals. Send proposals to:

Dr. Pam Marrone
Monsanto Agricultural Company
700 Chesterfield Village Parkway
Chesterfield, MO 63017

WRCC-60 Abstracts

Biochemistry of Fungal Resistance to Sterol Demethylation Inhibitors

The primary mode of action of DMI-compounds such as triadimefon, fenarimol or flusilazole is the inhibition of the C14-demethylation of 24-methylenedihydrolanosterol, both being early precursors of fungal sterol synthesis. The inhibition of this biosynthetic step leads to a drastic accumulation of the sterol precursor. Inhibition of fungal growth is mediated by the incorporation of this unsuitable sterol into fungal membranes, where they are thought to disturb membrane functions.

The development of field resistance to DMIs has been either rather slow (some powdery mildews) or has not yet effected disease control at all. This experience is different from former groups of fungicides with a single-site mode of action, and a different pattern of population dynamics and selection of resistant sub-populations might be responsible for this promising difference. However, uncertanties still exist with regard to the development of appropriate anti-resistance strategies. Predictions will be highly speculative if they are not based on rational explanations for the differences between DMIs and fungicides such as benzimidazoles or acylalanines, both of which encountered rapid development of field resistance. The clarification of the molecular mechanism of resistance is one of the parameters that will be important for the development of preventive strategies or novel countermeasures.

The model system currently under investigation is a set of *Ustilago* avenae -strains with different sensitivities to DMIs. Four resistant genotypes were randomly chosen from approximately 100 strains selected on triadimenol subsequent to UV-mutagenesis. All four resistant isolates are distinguished by growth rates similar to the wild-type strain. Cross-resistance to different groups of fungicides has been investigated. All four resistant strains are cross-resistant to 20 different DMIs. However, the resistance factors vary considerably, ranging from 50 (triadimenol) to 2 (miconazole). This variation indicates that some DMIs (low resistance factor) might still be useful in crop protection when the performance of others (high resistance factor) is already declining. The underlying biochemistry of these variable resistance factors is currently under investigation and might lead to DMIs not cross-resistant to former compounds. No cross-resistance was observed for morpholines, carboxamides and benzimidazoles. A surprising result was the presence of cross-resistance to nikkomycin, an inhibitor of chitin synthetase. This cross-resistance has no practical impact, but will be a valuable tool for studies on the molecular mechanism of resistance.

The major sterol of all strains is ergosterol irregardless of their DMI-sensitivity, and the plasma membrane is enriched in sterols. Thus, resistance is neither explained by an altered biosynthetic route of sterols nor by an altered deposition of the final product ergosterol. The dynamics of sterol synthesis (radioactive pulse-labelings of sterols) indicated that lanosterol demethylation is equally well inhibited in both the sensitive and resistant strains. Sterol precursors initially accumulate to an equal amount (Köller, submitted) suggesting that neither a decreased intracellular inhibitor concentration, nor an inhibitor segregation into vacuoles, nor a decreased affinity of the inhibitor to the target site, nor an increase number of target sites are suitable models to explain DMI-resistance. All of these mechanisms have been recently suggested. The initial accumulation of sterol precursors in resistant Ustilago -strains leads to a transient stop of growth (one cell cycle). A fast recovery of growth is accompanied by a rapid decline of sterol precursors (GC-analysis), although the target site remains blocked (pulse-labeling). These results suggest a mechanism of resistance based on the inducible degradation of (toxic) sterol precursors that accumulate under the action of DMIs.

Dr. Wolfram Koeller
New York State Agricultural Experiment Station
Dept. of Plant Pathology
D. W. Barton Laboratory
Geneva, NY 14456-0462

National Diamondback Moth (DBM) Resistance Project: DBM Behavioral Resistance

In support of a national program (coordinated by T. Shelton, NY) to assess regional differences in DBM susceptibility to insecticides, a project was established to provide supporting data for a range of populations collected from major crucifer growing areas of the U.S.

Objectives:

Using a monosize (on-demand) droplet generator in LPCAT, we are developing a bioassay technique to evaluate behavioral resistance of field collected *Plutella Xylostella* populations to precisely defined spray deposits that may be more accurately related to deposits encountered in field situations than traditional assays.

Methods and Materials:

Ambush, Monitor, and Lannate are being evaluated against 3rd instar larvae using their corresponding field rate dilution and the LC_{90} determined by collaborative leaf dip bioassays [WIS-Wyman, and LPCAT]. Populations previously subjected to standard bioassays are sent to Ohio and assayed in the following manner: mortality, irritability/repellency, dispersal and feeding damage are quantified 24 hr after exposure to spray deposits.

Uniformally-sized (80 in-flight diam) drops are applied at 5, 10, 20, 40 and 80 drops/cm^2 to cabbage leaf discs (5 cm^2). Drop density and gm AI/unit are calculated and correlated with other assay data for each population and each insecticide. A behavioral index is being identified and quantitative data is being collected for predictive computer models of "irritation," movement of treated surfaces, etc. The objective is an improved estimate of individual population behavioral responses which may better explain field performance of individual products.

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Mechanism of Insecticide Resistance in Colorado Potato Beetle (CPB): The Role of Microsomal Mixed Function Oxidase

To characterize the biochemical basis for a Michigan azinphosmethyl CPB resistant strain the role of microsomal mixed function oxidases (MFO) was studied. Oxidation of pyridine nuculeotide (NADPH) was observed and it occurred even in the absence of exogenous cytochrome-C in the susceptible (S) and in the resistant (R) strains, Long Island (R) and Macomb (Rm). Xenobiotic substrates or electron acceptors are not required for NADPH oxidation in these preparations. Oxidation by both the R strains was 2-3 fold greater than the S strain at higher time intervals and was linear up to 20 min. The oxidation levels in Rl was greater than in Rm strains. NADPH oxidation was stimulated (30-40% more) by exogenous cytochrome-C the oxidation levels were different, the R/S ratio remained the same in the Rl strains, both in the presence and absence of exogenous cytochrome-C.

In both the resistant strains SKF 525A, a synergist and known inhibitor of microsomal MFO'S, inhibited oxidation of NADPH 80-92% at a concentration of 2 x 10 (-3) M. A 50% inhibition was observed with 2 x 10^{-4} M SKF 525A. These findings confirm that electron transfer in the absence of exogenous electron acceptor proceeds via cytochrome P (450). Since the inhibition of NADPH-oxidation was substantially reversed by cytochrome-C, the inhibition is probable at the cytochrome P (450) level. The reversal of inhibition by cytochrome-C also indicates that electrons were accepted prior to cytochrome P (450) in the electron transfer chain. SKF 525A impact was concentration dependent in the absence of cytochrome-C in the S and Rl and Rm strains.

The results on cytochrome C-reductase indicate linear rates of enzyme activity up to 20 minutes in the S, Rl and Rm strains with a 2-fold greater activity in Rl and 6 fold greater activity in Rm than the S strain.

To further characterize the role of MFO's in CPB resistance to Azinphosmethyl, the oxidation catalyzed by microsomes were assessed by using different substrates representing different pathways of detoxification. The ration of both the R to S with regard to O-demethylation of paranitro anisol was 1.3-1.42 suggesting acceleration of O-dealkylation pathway in the R strains. Similarly aminopyrene demethylase representing the N-dealkylation pathway showed an R/S ratio of 1.8-2.1. Another entirely different but important pathway representing Epoxidation showed 120-140% greater activity in the Rl and Rm strains compared to the S strain.

In the CPB treated in vivo with synergists, only PBO could significantly inhibit microsomal NADPH oxidation when compared to DEF and DEM suggesting MFO influence. Further studies with Rl larvae reveal localization of MFO activity in the gut. Corroboration with the biochemical analysis and toxicological findings, suggests that PBO can readily synergize Azinphosmethyl with a synergism ratio of 14.9 (DEF 2.0 and DEM 1.1) thus strongly supporting our contention that the mechanisms of resistance in both the Rl and Rm strains are MFO based.

Kabeer Ahammad, Mark Whalon and Robert Hollingworth
Pesticide Research Center and Department of Entomology
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Progress Report on continuing studies of insecticide resistance in the Colorado potato beetle, *Leptinotarsa decemlineata*

Azinphosmethyl, permethrin, and avermectin resistance in Colorado potato beetle (CPB) continue to be investigated in our laboratory. A CPB strain from Massachusetts (MA-R) is 435-fold resistant to azinphosmethyl due to a single intermediately dominant, autosomal factor. An azinphosmethyl resistant strain (AZ-R) was bred that had this factor and genome 94% that of a susceptible strain. This strain was 136-fold resistant and had a relative biotic potential 83% that of the susceptible strain, but heterozygotes were as fit as the susceptible strain. DEF synergized both resistant and susceptible strains (MA-R SR 10), while DEM and PBO had only moderate levels of synergism in the resistant strains only (MA-R SR 2 & 4, respectively).

Permethrin resistance was 55-fold and was found to be due to a sex-linked, semirecessive factor. A permethrin resistant strain (PE-R) was bred that had this factor and a genome 94% that of the susceptible strain. This strain was 19-fold resistant and showed no fitness disadvantage. There were high levels of synergism to both PBO and DEF in susceptible and resistant strains. Both MA-R and PE-R strains showed cross resistance to cyfluthrin and fenvalerate.

Two strains of avermectin resistant CPB have been isolated using different techniques. The first strain was generated through the use of the mutagen ethyl methane sulfonate. The second strain was generated by heavy avermectin selection of an enclosed area of a potato field during the 1986-87 growing seasons. Studies are currently underway to determine the number of genes involved, allele dominance, and if there is any loss of fitness or cross resistance due to avermectin resistance.

A computer simulation model has been constructed, based on CPB resistance to these insecticides and life table parameters, to determine if insecticide rotation or mixture could be used to effectively delay resistance. The findings of this model are that while there is a slight advantage of the mixture strategy in certain situations, it is probably too minimal to be effective as a management technique.

Work currently underway in the laboratory includes analysis of the esteratic, glutathione-S-transferase, and oxidative activities of the various CPB strains in our laboratory through model substrates (i.e. napthyl acetate, DCNB, analine, etc.) and other spectrophotometric means (i.e. cytochrome P-450 peaks). We are also karyotyping the various CPB strains selected in our laboratory. We hope to soon be isolating the proteins responsible for insecticide resistance, particularly permethrin resistance, by various chromatographic means and use oligonucleotide fragments from this information to probe, isolate and clone the genes responsible for resistance in CPB.

Argentine, J. A., J. M. Clark, D. N. Ferro. 1988. Genetics and synergism of azinphosmethyl and permethrin resistance in the Colorado potato beetle (Coleoptera: Chrysomelidae). J. Econ. Ento. (in press)

Argentine, J. A., J. M. Clark, D. N. Ferro. 1988. Relative fitness of insecticide resistant strains of Colorado potato beetle (Coleoptera: Chrysomelidae). J. Econ. Ento. (submitted)

Argentine, J. A., J. M. Clark, D. N. Ferro. 1988. Computer simulation model of the evolution of insecticide resistance in the Colorado potato beetle (Coleoptera: Chrysomelidae): prospects for resistance management through insecticide mixture and insecticide rotation. Bull. of ESA (in manuscript)

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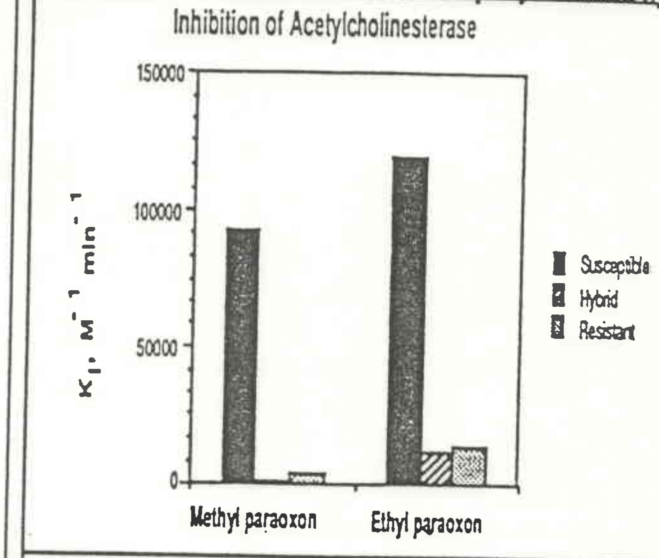
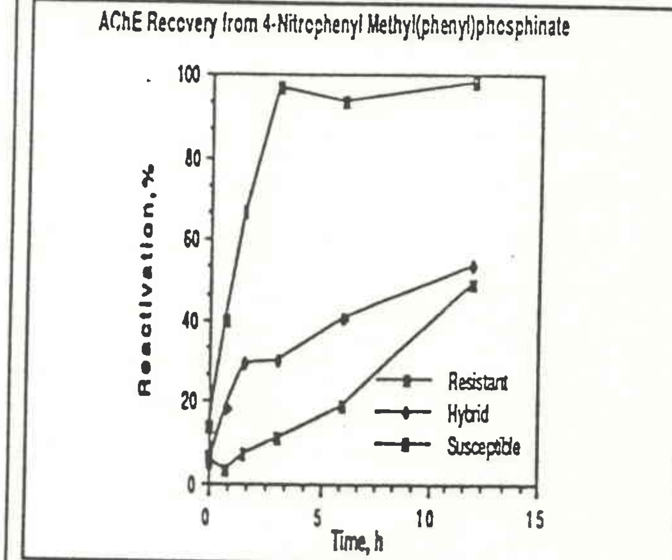
Insecticide Resistance Biochemistry and Genetics in Heliothis virescens

A pyrethroid resistant strain (RR) has been maintained for 14 generations including two series of backcrosses into a susceptible strain. This strain is used by Dr. David Heckel to test for linkage of permethrin resistance to seven candidate autosomal marker allozymes. Two other permethrin resistant strains, HSB and OC (Payne *et al.* 1988) are also maintained and selected about every fifth generation.

Organophosphate susceptibility was found in one family from tabacco. This family (FLJ7) exhibits about 50% increased developmental time of larvae and adults are very delayed in producing eggs. Acetylcholinesterase of the larvae CNS from FLJ7 is more rapidly inhibited by





methyl paraoxon (first figure) and slower to recover from organophosphinate inhibition (right figure) than a methyl parathion resistant strain (Woodrow 1983)

Reduced sensitivity to inhibition appeared to be dominant, while recovery was expressed differently in hybrids than in either strain. This method may be useful in identification of resistance genotypes. (From Abs. 2nd Intn'l Cong. ISSX, Kobe, Japan)

Brown, T. M. and G. T. Payne. 1988. Experimental selection for insecticide resistance. J. Econ. Entomol. 81:49-56.

Payne, G. T., R. G. Blenk and T. M. Brown. 1988. Inheritance of permethrin resistance in Heliothis virescens. J. Econ. Entomol. 81:65-73.

Brown, T. M. and W. G. Brogdon. 1987. Improved detection of insecticide resistance through conventional and molecular techniques. Ann. Rev. Entomol. 32:145-162.

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Monitoring Resistance in Populations Through Single Insect Assay

Research on the formulation of simple, sensitive biochemical diagnostic tests for the detection of specific resistance mechanisms in individual insects was conducted with emphasis on organophosphate resistance and the mechanisms of AChE insensitivity and of detoxication by esterases. The work was performed mainly on Culex spp., although agricultural pests were also investigated.

Seven diagnostic tests have resulted from this research todate: Five concern esterases, and two insensitive AChE. An additional procedure for quantification of protein in single insects was elaborated. The latter may be used in conjunction with the other tests to take into account variations in the size of the test insect. Three of the esterase tests developed ("Filter Paper Test", "Nitrocellulose Test" and "Microtitre Test") utilize the ability of these enzymes to hydrolyze naphthyl acetate. Two tests (Dot Blot and Elisa) involve immunological reactions. The tests for insensitive AChE (Microtitre Test and Nitrocellulose Test) utilize the difference in the inhibitory properties of carbamates and organophosphates on AChE of S and R strains.

The characteristics of each test were studied in mass homogenates of mosquitoes from laboratory strains with known resistance mechanisms, and were subsequently adapted for use on individual insects. Two of the esterase tests (FP and MT) and the AChE test (MT), were subsequently used on collections of Culex quinquefasciatus and C. pipiens from various countries of Europe, Africa, Asia and North America. A strong agreement was found in most cases between the results of the biochemical tests and those obtained with traditional methods of bioassay, diagnostic dose tests, and electrophoresis. The agreement concerned mainly the frequency of susceptible individuals in the test population, although the quantification of resistance was also possible under certain circumstances.

A simple, inexpensive test kit for esterases is now being tested by field personnal of Mosquito Abatement districts in California with a view to its wider distribution in the near future.

This research is being conducted collaboratively between my laboratory and that of Dr. Nicole Pasteur, CNRS, University of Montpellier, France. It is supported by the University of California Mosquito Research Program, the World Health Organization and a U.S. DAMD contract.

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Summary of 1987-1988 Resistance Research

I. Impact of Spider mite (Acari: Tetranychidae) Dispersal from Almonds on the Population Dynamics and Resistance Frequencies in Neighboring Cotton. (Beth Grafton-Cardwell)

In the four study sites, almonds were an early season source of *Tetranychus pacificus* for cotton. Spider mite outbreaks in almonds coincided with orchard water stress and followed applications of repellent acaricides. Aerial dispersal into cotton significantly increased the density of *T. pacificus* in the 150 rows closest to almonds. Acaricide resistance frequencies of cotton spider mites were only temporarily affected by dispersal from almonds since cotton spider mite populations were already well established and acaricides were applied close to the time of dispersal. The major impact of almonds on cotton was as an overwintering host for resistant *T. pacificus*.

II. Evaluation of Insecticide Resistance in *Aphis Gossypii* Infesting Cotton. (Beth Grafton-Cardwell)

Residual leaf bioassays will be used to characterize insecticide resistance in the adults and nymphs of the cotton aphid. Cotton aphids will be collected from various sites in the San Joaquin Valley, California to determine the range of response to 6 insecticides.

III. Acaricide Resistance Management in California Almonds. (Melody Keena)

Commercial applications of propargite (Omite) were found to control *Tetranychus urticae* and *T. pacificus* populations that had very high frequencies of resistance, if good coverage was achieved, and predatory mites were present. Propargite resistance detected in the laboratory was found to be masked or reduced in field collected spider mites, thus resistance had little effect on field efficacy. Cyhexatin (Plictran) and fenbutatin-oxide (Vendex) resistance in field collected spider mites and its influence on efficacy were less predictable.

IV. Preregistration Resistance Management for Hexythiazox (Savey). (Melody Keena)

Baseline data on the susceptibility of *Tetranychus* Spp. to hexythiazox using various bioassay methods is being collected. A simplified resistance detection method is being developed and will be used to survey spider mites susceptibilities to hexythiazox from several crops, for which registration is being sought. Preliminary results indicate that low frequencies of hexythiazox resistance can be detected in spider mite populations that have never been exposed to it.

V. Evaluation of Acaricide Resistance in Tetranychus urticae and Panonychus ulmi in California Pears. (Tongyan Tian)

Residual leaf bioassays were used to characterize cyhexatin and fenbutatin-oxide resistance in *T. urticae* and *P. ulmi*. *P. ulmi* resistance frequencies ranged from susceptible to highly resistant and varied between orchards in all counties surveyed. In contrast, widespread resistance of *T. urticae* to cyhexatin and fenbutatin-oxide was found in the northern region and susceptibility was found in the southern region of the pear growing area. Research to determine what influence spider mite migration from field crops has on resistance in these two regions is planned. In addition, field efficacy of the new acaricides, clofentezine and abamectin, in pears is being evaluated.

VI. Characterization of insecticide Resistance in the Greenhouse Whitefly *Trialeurodes vaporariorum*. (Amir Omer)

Effects of two organophosphorous insecticides and a pyrethroid on larval and adult stages of the greenhouse whitefly are being studied.

VII. Recent Resistance Publications

Dennehy, T. J., E. E. Grafton-Cardwell, J. Granett & K. Barbour. 1987. Practitioner-assessable bioassay for detection of dicofol resistance in spider mites (Acari: Tetranychidae). J. Econ. Entomol. 80: 998-1003.

Grafton-Cardwell, E. E., J. Granett & T. F. Leigh. 1987. Spider mite species (Acari: Tetranychidae) response to propargite: basis for an acaricide resistance management program. J. Econ. Entomol. 80: 579-587.

Grafton-Cardwell, E. E., T. J. Dennehy & J. Granett. 1987. Quick tests for pesticide resistance in spider mites. Calif. Agric. 41: 8-10.

Grafton-Cardwell, E. E., T. J. Dennehy, J. Granett & S. M. Normington. 1987. Managing dicofol and propargite resistance in spider mites infesting San Joaquin Valley cotton. UC IPM Publ. 5. 10pp.

Grafton-Cardwell, E. E., J. A. Eash & J. Granett. 1988. Isozyme differentiation of *Tetranychus pacificul* from *T. urticae* and *T. turkestani* (Acari: Tetranychidae) in laboratory and field populations. J. Econ. Entomol. 81: 770-775.

Keena, M. A. & J. Granett. 1985. Variability in toxicity of propargite to spider mites (Acari: Tetranychidae) from California almonds. J. Econ. Entomol. 78: 1212-1216.

1987. Cyhexatin and propargite resistance in populations of spider mites (Acari: Tetranychidae) from California almonds. J. Econ. Entomol. 80: 560-564.

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More Linkage Mapping in the Tobacco Budworm Heliothis virescens

In the last year, ten enzyme-encoding loci have been studied in the tobacco budworm in an attempt to assign them to linkage groups. The main result is that at this point, approximately 25% of the tobacco budworm genome is linked to one of these enzyme marker loci. This has enabled us to begin a detailed linkage analysis of pyrethroid resistance in a laboratory selected strain.

Three loci are sex-linked: TPI (triose phosphate isomerase), AcP (acid phosphatase), and 6PGnDH (6-phosphogluconate dehydrogenase). TPI and AcP are loosely linked, with a crossover rate of approximately 28%. Crossing-over between 6PGnDH and the other two sex-linked loci has not yet been measured.

Seven loci are autosomally inherited. Since no previous linkage results existed for tobacco budworm, it was necessary to examine all 21 possible pairwise combinations of these 7 loci to test for linkage between them. At this point 19 of these have been examined, with the female as the informative parent in each case. Our working hypothesis is that there is no crossing-over in famales (this seems to be the rule in Lepidoptera), so such matings should clearly show autosomal linkage if it exists. The results are that every one of the 19 tests yielded free recombination. Two pairs remain to be examined, but the evidence is that the four loci involved are unlinked to the other three. The seven autosomal loci are therfore distributed on at least five separate chromosomes, and perhaps as many as seven. This is a small but significant fraction of the total of 30 autosomes in this species. The loci are phosphoglucomutase, mannose phosphate isomerase, aconitase, isocitrate dehydrogenase (two loci), phosphoglucose isomerase, and tetrazolium oxidase.

Several other polymorphic enzyme loci are currently being investigated. In addition, our collaborative efforts with Dr. A. G. Abbott, a molecular geneticist at Clemson, have yielded several DNA RFLPs (restriction fragment length polymorphisms) that we will eventually add to the linkage map. Crosses with *Heliothis subflexa* have also been successful, so we will be able to use genetic markers from that species as well. At this point there is no doubt as to the feasibility of constructing a saturated genetic linkage map for the tobacco budworm.

We have begun using these marker loci to study the genetics of pyrethroid resistance. Crosses between marker strains and the highly resistant "RR" strain of Dr. T. M. Brown (Department of Entomology, Clemson University) were set up and the hybrids backcrossed to the RR strain. However, in the middle of this process, it became apparent that the RR strain had lost much of its resistance. (It had, in fact, been maintained without selection for several generations.) The very high susceptibility of the backcross larvae confirmed this--all families were killed by what should have been a diagnostic dose enabling half the progeny (resistant homozygotes) to survive. Thus, no linkage information could be derived from these crosses. Remarkably, following two generations of selection, resistance levels in the RR strain returned to their normal high levels. Another round of crosses with the marker strains is currently in progress.

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Status of Mite Resistance in California

Tetranychus pacificus:

Propargite resistance in the Pacific spider mite is stable under greenhouse conditions for at least five months. The mode of inheritance is consistent with a major semirecessive gene model. An analysis of cyhexatin and fenbutatin-oxide resistance mode of inheritance was reported in: Hoy, M.A., J. conley and W. Robinson. 1988. Cyhexatin and fenbutatin-oxide resistance in Pacific spider mite (Acari: Tetranychidae): Stability and mode of inheritance. J. Econ. Entomol. 81 (1): 57-64.

Metaseiulus occidentalis:

A colony was selected for resistance to abamectin. The resistance achieved was modest, as measured by survival of adult females, but egg deposition by females was enhanced over the unselcted colonies. These data will be reported in: Hoy, M. A. and Y. L. Ouyang. 1988. Selection of the western predatory mite, *Metaseiulus occidentalis* (Acari: Phytoseiidae), for resistance to abamectin. J. Econ. Entomol. (in press).

The diversity of resistance in *M. occidentalis* appears to rival that of many pest arthropods; resistances to organophosphates, carbamates, pyrethroids, sulfur, and now abamectin have been obtained through laboratory or field selections. The abamectin-resistant strain could be of practical value in an IPM program.

Trioxys pallidus:

Selection for azinphosmethyl resistance has yielded a strain with a potentially useful level of resistance. The resistant strain is being released into four walnut orchards in California during the 1988 field season to evaluate whether it can establish, survive field rates of azinphosmethyl, and control the walnut aphid. A paper on the selection is in press: Hoy, M.A. and F.E. Cave. 1988. Guthion-resistant strain of walnut aphid parasite. California Agriculture (July/August issue).

Aphytis melinus:

The laboratory-selected carbaryl-resistant strain of *A. Melinus* will be released into citrus orchards during 1988-1989 to evaluate its ability to establish, survive carbaryl and control California red scale. Publications include:

Rosenheim, J.A. and M.A. Hoy. 1986. Intraspecific variation in levels of pesticide resistance in field populations of a parasitoid, Aphytis melinus (Hymenoptera: Aphelinidae): The role of past selection pressures. J. Econ. Entomol. 79: 1161-1173.

Rosenheim, J.A. and M.A. Hoy. 1988. Sublethal effects of pesticides on the parasitoid Aphytis melinus (Hyenoptera: Aphelindae). J. Econ. Entomol. 81(2): 476-483.

Rosenheim, J.A. and M.A. Hoy. (in press). Genetic improvement of a parasitoid biological control agent: Artificial selection for insecticide resistance in Aphytis melinus (Hymenoptera: Aphelinidae). J. Econ. Entomol.

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Monitoring Levels of Resistance to Azinphosmethyl in Platynota idaeusalis, an Important Pest of Apple, in Seven Eastern States

This year our primary emphasis has been in monitoring levels of resistance to azinphosmethyl in populations of tufted apple bud moth (TABM), Platynota idaeusalis (Walker) throughout its range in the eastern U.S. TABM is the most serious direct pest of apples in the 5-state Cumberland-Shenandoah region of the eastern U.S. The estimated loss due to TABM damage for growers in this region in 1985 exceeded $4 million. However, its relative importance to growers varies geographically. For example, in Greene County located in western Pennsylvania, pheromone trap catches are often the highest reported in the state, but percent fruit injury is very low. In Adams County, located in southcentral Pennsylvania, the average fruit injury from TABM has increased from 4% in 1973 to 3% in 1979, and to over 6% in 1986. Increased levels of resistance to OP insecticides in TABM have been detected in populations within this region and may be responsible for these apparent increases in fruit injury. At present, little effort to monitor OP resistance outside Adams County, Pennsylvania has been made. Reports from North Carolina and West Virginia suggest that TABM is becoming a more serious pest for many growers in these regions. TABM populations in Georgia, Deleware, New Jersey, and New York are generally not a significant problem for growers.

This summer, levels of resistance to azinphosmethyl in TABM populations are being monitored in 19 orchards in Georgia, North Carolina, West Virginia, New Jersey, Pennsylvania, Deleware, and New York using insecticide-incorporated stickum in pheromone-baited delta traps. The results demonstrate that azinphosmethyl-susceptible populations of TABM exist in Deleware, New Jersey, North Carolina, and in Pennsylvania orchards outside of Adams County. The correlation of resistance levels in each orchard with seasonal pesticide use and management practices, daily trap catch, egg mass density, fruit injury, and the surrounding habitat structure outside or orchards will be evaluated at the end of the season.

This study is allowing us to investigate the potential of sex pheromone traps to serve as reliable, inexpensive tools to monitor resistance in mobile insect populations. Secondly, it is providing a current assessment of resistance levels to azinphosmethyl throughout the geographical range of TABM. Early detection in areas where TABM remains susceptible may help avoid or delay the development of resistance by allowing pest managers to fashion more assiduously tailored spray programs. Finally, this project is providing a mechanism to exchange information and coordinate efforts of scientists in different states at a regional level to manage TABM on apple in the eastern U.S.

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Pesticide Resistance in Greenbugs:

Field studies were conducted to determine if continuous exposure to the systemic insecticides, aldicarb, carbofuran, disulfoton, and terbufos would induce or select for insecticide resistant greenbugs. Resistance was determined using a surface residue LC50 bioassay for each of the insecticides. The LC50 values from resistant greenbugs were compared to LC50 values from susceptible greenbugs for each insecticide. Non-overlapping 95% fiducial limits indicated a significant difference between the LC50's from the susceptible versus resistant greenbugs. In field studies greenbug populations exhibited 21 to 104-fold increased resistance to disulfoton. The greenbugs exposed to the other insecticides did not exhibit significant increases in resistance.

Greenhouse studies were initiated to determine if insecticide resistance was due to a genetic response within the greenbug clones or simply the selection of resistant genotypes from a genetically diverse population. Greenbugs originating from a single insecticide susceptible aphid developed 65 to 300-fold increases in resistance. Similar results were obtained when the study was repeated using progeny from a different greenbug. This indicates that a mechanism other than selection was responsible for the insecticide resistance. Insecticide resistant greenbugs were tested for cross resistance to carbofuran, dimethoate, malathion and terbufos. There was a significant (P .05) increase in cross-resistance to dimethoate (10-fold) and terbufos (2-fold), but no significant cross resistance to carbofuran and malathion. The resistant greenbugs maintained ca. 75-fold level of resistance to disulfoton, as compared to the susceptible greenbugs, throughout the study.

In a comparison study, greenbugs were examined electrophoretically to determine if insecticide resistance could be correlated with increased esterase activity. The insecticide's dailkylphosphoryl group was liberated from the esterase(s) prior to staining in order to obtain optimum activity. The liberation was accomplished by either of the following methods: incubating greenbug supernatant with pyridine-2-aldoxime methiodide (2-PAM) prior to electrophoresis; or using greenbugs that were removed from insecticide selection pressure for up to three months. The use of these techniques detected a qualitative (more intensely stained band) difference between insecticide resistant and susceptible greenbugs.

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Pesticide Resistance in the Spider Mites of Corn:

The study of variation in resistance in Banks grass mite and twospotted spider mite is continuing in 1988. The current emphasis is on the influence of the condition of host plant and environmental variables. This study is cooperative with D.C. Margolies, Kansas State I and F. B. Peairs and S. L. Miller, Colorado Stat sity.

Dr. T. O. Holtzer and
Universit

Pyrethroids Efficacy Group (PEG Update on PEG-US/University Pyrethroid Monitoring Program (<u>Heliothis virescens</u> in the U.S. Co Belt

As a result of observations of increased synthet pyrethroid tolerance in Heliothis virescens in cotton belt during 1985 and 1986, the U.S. compa volved with pyrethroids (E.I. DuPont & Co., FM poration, Hoechst-Roussel Agri-Vet, ICI Americ Mobay) formed an inter-company technical grou US). The major goals of this group during 1987 a have been to evaluate the resistance situation in t belt through intensive monitoring, evaluate differ monitoring techniques and to put forward a serie pyrethroid-use guidelines based on the informati tained from the monitoring programs. Numerous sity researchers throughout the cotton belt have contributed immensely to this effort.

The monitoring techniques used during 1987 the Adult Vial Test (AVT) developed by Dr. F. V (2) a foliar spray /1st instar test developed by ICI the topical test on 3rd instars. The AVT was a fie monitoring technique while the other 2 tests were ducted in the laboratory on field collected sample than 42,000 adults and larvae were tested during 1 PEG-US. In addition, university personnel condu AVT on approximately 25,000 adults (F. W. Plapp commun.).

<u>The major conclusions reached following the 1987 season were:</u>

- In general, the expectations based on the 198 of wide-scale field control failures were not Except for a few 'hot spots' in Texas and particular the Brazos area late in the season) t levels were similar to previous years. This r not led to complacence. In fact, during 198 intense collaborative monitoring program public and private agencies has been implem
- Populations west of Mississippi had higher t levels than those from eastern states. Season tion in the AVT was seen in Arkansas, Louisi Mississippi. In general, tolerance levels in a creased in mid-August and lasted through week in September. Tolerance levels then drc early season values.
- There was a general agreement between each test methods used during 1987. There seems place for each method in a wide-area monitor gram. The ease of collecting and testing large

makes the AVT very suitable for field monitoring to target problem areas when combined with field efficacy information. Once these areas are identified, the foliar and/or topical tests on field collected samples can more precisely define tolerance levels and confirm the presence of resistant populations.

- A list of pyrethroid-use guidelines emphasizing the limited use of pyrethroids (in-line with the Texas and mid-south programs) were issued by PEG-US at the 1987 Beltwide Cotton Conferences and published in the February issue of Cotton Grower.

The *Heliothis* monitoring program is continuing during 1988, with PEG-US supplementing many of the efforts by state university researchers. The practical value of a resistance monitoring program is measured by how well it reflects the actual field situation. Therefore, a major goal during 1988 is to gain a better understanding of the relationship between monitoring results and field efficacy.

[1]Technical representatives from E. I. DuPont, FMC, Mobay, Hoechst-Roussel and ICI.

Drs. S. L. Riley, I. A. Watkinson, C. A. staetz, D. E. Simonet, J. R. Whitehead, R. Blenk, R. J. Gouger, M. D. Collins
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Genetics and Detection of Pesticide Resistance in Colorado Potato Beetle

The development of pesticide resistance is a major obstacle to IPM programs for Colorado potato beetles (CPB). We are attempting to develop systems to improve monitoring for resistance in CPB to avoid wasteful applications of pesticides that have become ineffective as a result of resistance. Our long-term objective is to use these techniques and information on the genetics of resistance to design integrated approaches to maintain pesticide susceptibility so that pesticides will be maximally effective when they are necessary.

Topical assays seem to be at least as efficient for monitoring resistance in adult CPB as residual assays. A residual assay technique for first instar larvae, suggested to use by Dr. George Kennedy of North Carolina State University, appears to give less variable results than the adult tests. CPB from Main, long used for susceptible strains by researchers in the eastern U.S., no longer appear to be fully susceptible to pesticides. A susceptible strain was isolated from northwestern Iowa, however. As expected, CPB from Long Island, New York, were highly resistant to all pesticides tested. Larvae of these strains have been exposed to field rates of azinphosmethyl and fenvalerate on potato plants in the laboratory. The survival on these treated plants of second through fourth instar larvae from resistant (Long Island) and susceptible (Iowa) strains correlates closely with he resistance measured in the adults of the same strain.

These studies also show that selection for resistance (discrimination between resistant and susceptible genotypes) seems to occur across all larval instars in addition to the adults. This is in contrast to other species in which resistance frequently evolves (e.g., in *Heliothis)*, where selection is usually limited just to the adults or a few instars, and provides at least a partial explanation for the rapid rate of selection for resistance in CPB compared to most other pests. Genetic crosses are now in progress to establish mode of the inheritance of resistance to several pesticides.

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Implicatins of Alternations or Mosaics for Resistance Evolution

Given two or more insecticides with unique modes of action and metabolism, one could alternate their use in time either in the short term ("alternations" or "rotations") or long term ("sequential introduction"), or alternate their use in space ("mosaics"), or use them in combination ("mixtures"). Although it has recently been proposed that mosaics be used for management of resistance in the horn fly, genetic simulation models and experiments with Aedes aegypti show that alternations will always be as about as good as or better than mosaics. Under the extreme circumstances of complete absence of refuges for susceptibility, such as in the case of the horn fly, alternations may be better than mosaics by as many times as there are unique pesticides. The relative benefits of alternations are greatest in those cases where resistance is most likely to occur, that is, where there is high dominance of resistance and in the absence of refuges. Alternations are probably about two-fold better than mosaics on average. As a resistance management tactic, alternations are likely to be more easily implemented than mosaics.

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Pyrethroid Resistance in the Tobacco Budworm

Studies were conducted on the interactions of chlordimeform (CDF) and pyrethroids relative to pyrethroid uptake by larvae of the tobacco budworm. Also studied were the mechanisms of resistance in a pyrethroid resistant strain (ICI-R-87) of the tobacco budworm. Compared to the LSU-Lab strain, the ICI-R pyrethroid resistant strain was 2905 and 150 times less susceptible to cypermethrin and lambda-cyhalothrin, respectively.

The effect of CDF on permethrin and lambda-cyhalothrin uptake from a treated surface by pyrethroid susceptible (LSU-lab strain) and resistance (ICI-R) third instar larvae of the tobacco budworm was determined 3, 6 and 18 posttreatment. In general, CDF increased the uptake of both pyrethroids, especially in pyrethroid resistant

(ICI-R) tobacco budworms. Interestingly, at a given dose of either permethrin or lambda-cyhalothrin, larvae of the LSU-Lab strain consistently picked up more pyrethroid than did the ICI-R strain. These observations are not surprising if the resistant larvae have a reduced sensitivity to the pyrethroids, as appears to be the case. Thus, in the presence of a 72 hr. LD50 dose for susceptible larvae, the pyrethroid resistant larvae will be less stimulated to move and, therefore, less likely to pick up pyrethroid from a treated surface.

The factors contributing to pyrethroid resistance in the ICI-R strain were investigated using several techniques. A hot-probe bioassay for knock-down resistance (kdr) (Bloomquist & Miller 1985) using three pyrethroids (permethrin, cypermethrin and lambda-cyhalothrin) indicate that the ICI-R strain takes much longer for knock-down to occur than the LSU Lab strain. These observations suggest the presence of kdr in the ICI-R strain. In addition, the ICI-R strain also has ca. 4-fold higher titers of trans-permethrin hydrolase activity. The role of metabolism in pyrethroid resistant tobacco budworm larvae was evaluated by topically treating third instar larvae with C14 radiolabeled permethrin or lambda-cyhalothrin. At 18 hr posttreatment, the resistant larvae treated with permethrin had less total radiolabeled material internal, and less parent than did the susceptible larvae. However, for lambda-cyhalothrin treated larvae there was little difference between the two strains in the amount of total internal radiolabel or in the amount of parent. Thus, there appears to be some differences in how the resistant strain handles permethrin and lambda-cyhalothrin. The above studies suggest that kdr, an increased metabolic capability and, perhaps a reduced level of larval activity in the presence of the pyrethroids, all contribute to pyrethroid resistance in the ICI-R strain of the tobacco budworm.

The responses of over 1100 tobacco budworm male moths collected in Louisiana from May 10 through June 23 to cypermethrin (using Dr. Bill Plapp's treated vial technique) indicate that the pyrethroid resistance management program recommended and adopted by Arkansas, Louisiana and Mississippi during 1987 and 1988 was successful in helping reduce resistant genotypes. During August and September 1986, survival of male moths in vials dosed with 10 g of cypermethrin was 33-37%. During 1987, survival at the same does was 20, 13, 18, 12 and 15% for males collected during May, June, July, August and September, respectively. For May and June 1988, survival at the same dose was 12 and 5%, respectively.

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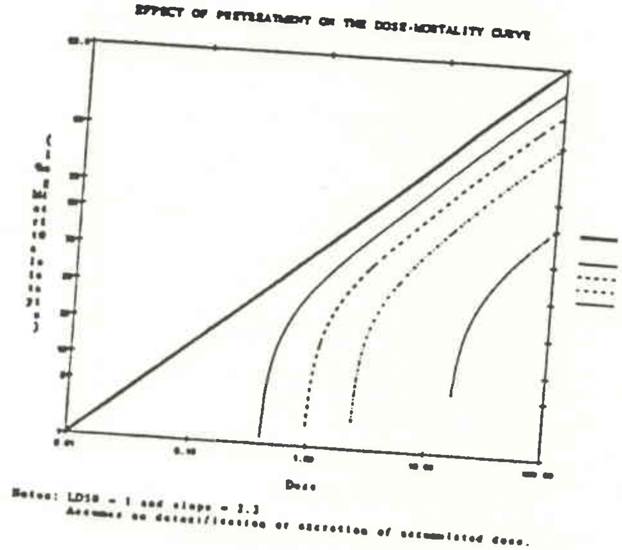
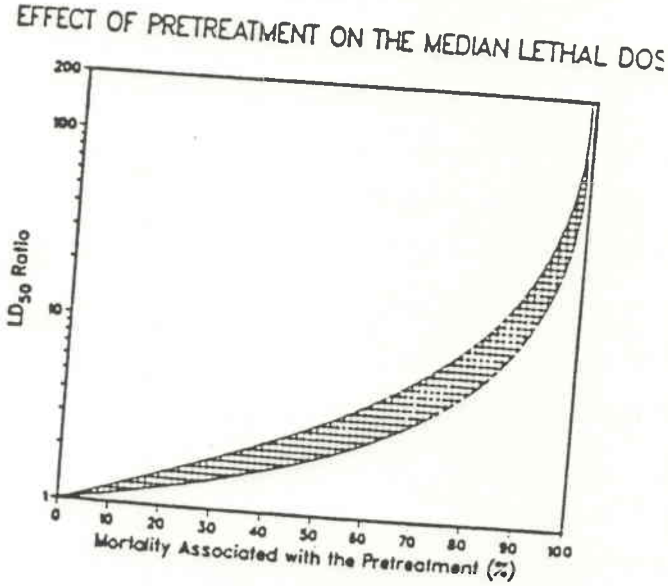
Theoretical Calculations of the Effects of Pesticide treatment on the Dose-Response Curve of the Survivors

Theoretical calculations were conducted to investigate the expected shape of the dose-response curve of survivors of a "susceptible" population that had been exposed to a pesticide treatment. This study was initiated to investigate factors that might influence variability in field monitoring programs.





It was assumed that the lethal doses within the population were logistically (i.e. logit) distributed, a subject's tolerance did not change after surviving a dose, and some or all of the dose may be accumulated.

Figure 1 shows the change in the dose-response curve with pretreatment to increasing doses, and Figure 2 shows the expected ratio of the LD50 of the survivors to the original population (shaded area: no accumulation to complete accumulation). The results show that survivors may appear to be more tolerant than the pretreated population. However, no biological data has been generated to test these results.

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Insecticide Resistance in Diamondback Moth (Plutella xylostella).

Tolerance to the pyrethroid fenvalerate in a diamondback moth populations was analyzed by quantitative genetic techniques. F1 offspring of field-collected individuals were reared in the laboratory as full sibling families and tested for tolerance to fenvalerate residues. Mortality varied extensively among families, indicating a genetic component. Variation in mortality at 48 h was essentially continuous and not significantly different from a normal distribution, suggesting that the heritable variation is polygenic. Heritability of fenvalerate tolerance was approximately 0.20. Results from probit analysis suggest that substantial variation in insecticide tolerance is common within insect populations. Quantitative genetic techniques may be useful for estimating the genetic component of variation in tolerance within populations.

Adults of the diamondback moth can detoxify themselves by auto-amputation after tarsal contact with insecticide residues. Up to 74% of moths autotomized one or both metathoracic legs after tarsal contact with insecticide residues. Scanning electron microscopy showed a smooth abscission at the joint between the trochanter and femur. In comparison to moths retaining all their legs, those that autotomized hd a higher rate of recovery, lower mortality, and 23% less insecticide in their bodies. The concentration of fenvalerate in autotomized legs were 15 times greater than in moth bodies. These findings suggest that the leg-drop response reduces the toxic effects of insecticide residues by eliminating part of the dosage. Genetic variation for this response was detected among Hawaiian diamondback moth populations.

Resistance levels in field populations are being monitored to test predictions from simulation model.

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Insecticide Resistance in Liriomyza leafminers and natural enemies:

We are initiating a project in collaboration with Jay Rosenheim to develop pyrethroid-resistant strains of the leafminer parasitoid *Diglyphus begini*. Our objectives are to: 1) measure variation in resistance among field populations in Hawaii, 2) determine the potential to increase pyrethroid resistance by lab selection and mutagenesis, and 3) determine the effects of selection on fitness of the parasitoid.

Resistance levels in field populations are being monitored to test predictions from a simulated model.

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Pesticide Resistance and its Management in the Sweetpotato Whitefly, Bemisia tabaci, in California

In previous studies of insecticide resistance completed during 1985-1987 (Prabhaker *et al*, 1985; 1988; Horowitz *et al*, 1988), we have concluded that field populations of *B. tabaci* in the Imperial Valley, California, USA, are highly resistant to a number of organophosphates and pyrethroids. Resistance levels have been increasing since the first measurements were made in 1983.

Resistant management may be an important strategy in effective whitefly control. We mention below some of our findings and also current and future research on management of resistant whiteflies.

1. Augmentation of traditional insecticides with synergists such as DEF and PB. Our results indicate combination of synergists with certain OPs and pyrethroids, significantly increases the toxicity of each insecticide in greenhouse and field trials (Prabhaker *et al*, 1988; Horowitz *et al*, 1988).

2. Directing insecticides against larval stages in addition to treatment of adults. The greatest activity of insecticides is against the first and second larval stages. With increasing larval age, there is a decrease in sensitivity to insecticides (Prabhaker *et al*, 1988, In Press).

3. Use of natural chemicals with a unique mode of action, such as neem seed extract (NSE) isolated from the seeds of the neem tree, *Azadirachta indica*. Activity of NSE against *B. tabaci* was measured by ovipositional

response and changes in adult development. NSE reduced oviposition and egg viability up to 98%. It also reduced the proposition of immatures successfully completing development to the adult stage.

4. Experiments are underway to test NSE as an antifeedant and/or repellent against *B. tabaci*, affecting transmission of plant viruses.

5. Resistance monitoring is being maintained to manage resistance to detect shifts in susceptibility within a population. Yellow sticky cards sprayed with insecticide are being used for this purpose. This technique enables rapid monitoring in many location.

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