Pesticide Resistance Management

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

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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 Coordinating 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.

The 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, and other regular features. This is the second newsletter and we have an international mailing list of approximately 1200.

We welcome suggestions for the improvement of the *Resistance Management Newsletter*. We also encourage recipients of the newsletter working on resistance to submit articles for publication in our next issue.

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 responsibility for the credibility of the significance of their data and observations. They must disclose fully the extent to which they have supporting data and confirmation of resistance. The editor 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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Submitting Contributions

Please limit your contribution to two pages or 1200 words. We will accept your contribution for the newsletter on a disk providing you are using an IBM or compatible system. Files created with WordStar 3, 4, 5, Microsoft Word, WordPerfect 4 and 5, Xywrite, Multi-Mate and DCA can easily be read into our desk top publisher. If you are using a word processor other than those mentioned you may provide us with an ASCII file. We encourage graphics for the newsletter. We will accept line art files in GEM, AutoCad.SLD, Lotus.PIC, MentorGR, Postscript, MS Windows, and HPGL format, as will any that are saved as meta files (universal graphics code).

You may also send your files via BITNET to 15360MGR @ MSU BITNET.

MacIntosh files that are produced in Microsoft Work can be saved in the MacIntosh Microsoft Word program by specifying the file is to be saved for PC use. These files can also be forwarded to us.

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Contents

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Annual Meeting: August 20, 1989, Richmond Virginia, U.S.A.

The WRCC-60 annual meeting will be held in conjunction with the American Phytopathological Society (APS) meeting in Richmond VA, U.S.A. on August 20, from 1:30 to 4:30 p.m. We will meet in Salon H of the Richmond Marriott Hotel. Everyone interested in pesticide resistance and host plant resistance is welcome to come and participate. The preliminary agenda will include several committees and working group reports, as well as, discussion for improvement of the *Resistance Management Newsletter*, resistance episodes, current research advancements, funding possibilities, future meetings and symposia, etc. There will also be opportunities to interact in small groups with other individuals working on resistance in different pesticide groups and/or organisms. Please bring written abstracts of your research progress since the last meeting. Abstracts should be up to 2 pages text plus any graphs you may have and should include a title, author(s) and affiliation.

Our specific objective for having the annual meeting with different professional societies each year is to facilitate greater communication and cross disciplinary involvement in WRCC-60. We hope that many phytopathologists will take advantage of this opportunity to participate. Since this newsletter reaches only a small fraction of those that will be attending the APS meeting, the burden of informing other interested resistance workers falls upon you phytopathologists receiving this newsletter. **Please get the word out and encourage other resistance workers to attend.** Help make this year's APS-WRCC-60 meeting a success!

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USDA's Role in Resistance Management

National debate over the use of pesticides in the production and processing of our food supply has taken on proportions of magnitude similar to those which exist in the use of nuclear power. Essentially, the same concerned interest groups are involved in both causes and human health is the basic issue. Without taking sides on the controversy between environmental and economic risks in using agrichemicals, I would suggest we begin to focus more of our attention on an insidious and age-old issue concerning the control of weeds and insects. I am referring to the fact that some of our safest and most effective insecticides and herbicides are becoming ineffective because pests are now more resistant to chemical controls. Unless a significant increase in the level of investment in research and other resources is undertaken soon, controversy regarding the use of chemicals in agriculture may become moot.

This observation is not designed to alarm farmers and other users, but rather to send an alert that time may be running out on our ability to rely upon chemicals as a major control agent. As stated in a recent publication[1], pest organisms, like most other life forms, are able to adjust to adverse environmental conditions by basic evolutionary processes. They can develop resistance to chemical pesticides, to natural or genetically altered defense mechanisms in crop plants, and eventually to some biological and cultural controls."

The fact is that agriculture has a ticking time bomb far more relentless than cancellation proceedings by regulatory agencies.

There may only be a few options open to our industry. One would be to sharply lower the dependence on chemical controls with emphasis on Integrated Pest Management (IPM) type strategies. Another opinion would be to sharply increase the level of support for research on resistance to controls by plants and animals. A review of current funding for research on resistance being carried out in Federal and university laboratories indicates a relatively low level of support and spending by the pesticide industry, though more, appears to be equally limited. To do nothing and hope for the best is probably an option, but the price for inaction might be inordinately high to producers and consumers alike.

What to do? One action plan has been put forward by the National Research Council[2] that identified four research strategies. The goal of their action plan would be to extend the useful life of existing control agents through the development of management strategies and tactics, and further, to intensify the discovery of new materials that would be safe and effective. The cost would be high, but when compared with field losses to crops, the investment needed is minuscule.

The advent of biotechnology and the use of molecular biology to isolate gene products responsible for resistance and also implementation of IPM technology are just two of many strategies which need to be accelerated if this country is to maintain an abundant and quality food supply. These newest of research tools have renewed interest among scientists that this serious problem associated with pest resistance can be conquered.

The role of USDA in this critical issue may be multifaceted. As the primary federal agency for promoting the production of food, feed, and fiber, the department has to be concerned with the involvement in solving the problem. It might best proceed in the form of a joint venture among federal, state, and university interests, the pesticide industry, and national commodity organizations. Every entity noted above has a fundamental stake in a successful solution and any solution will be expensive and time consuming. Agriculture and its support partners can't do less than give it a strong effort.

[1]Management of Resistance to Pest Control Agents: A Plan for Action, The Experiment Station Committee on Organization and Policy, June 1989, p.2.

[2]Pesticide Resistance, Strategies and Tactics for Management, National Academy Press, 1986, 471 pp.

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Host Plant Resistance, Pesticide Resistance and Genetic Engineering

Host plant resistance (HPR) is one means of protecting agricultural plants from stress. The formal origins of HPR are firmly but rather independently entrenched in the disciplines of Plant Pathology, Entomology and Agronomy. Deliberate attempts to manage and breed plants for HPR and to understand the underlying processes responsible for HPR date to the past century. A new field, Genetic Engineering, is on the verge of entering the fray and promises to revolutionize the subdiscipline of HPR. Ideally, these scientists should find a cohesive established body of knowledge in place that will allow them to interface their contributions easily and to communicate clearly with traditional HPR scientists. This is not the case and if HPR is to realize its potential in plant protection these limitations should be realized early in the process.

The conventional approach to using HPR has been to encounter an epidemic and then to find a source of resistance, incorporate the resistance into an agriculturally useful plant and deploy that plant variety in farmers fields until another epidemic occurs. The best known HPR systems are those like potato late blight, wheat rust and Hessian fly (Table 1) where HPR works, yet, the rate of failure occurs often enough to keep active programs on the treadmill. Grape phylloxera (Table 1), by contrast, was controlled almost immediately by introduction of resistant rootstocks from the US and very little investigation has been conducted on this pest since. This exercise results in a continuing, if intermittent, supply of resistant cultivars to replace those rendered susceptible by virulent pests, but this process doesn't provide much progress in developing an understanding of HPR that will eliminate the treadmill.

Some limited generalities have emerged from this work. Research by Flor on flax and flax rust showed that resistance to rust could be conferred by a single gene in the host that could in turn be overcome by a single gene in the pathogen. This is the gene-for-gene hypothesis and hundreds of genetic correspondences have been shown for a number of plant/pathogen systems. Browning studied small grain/rust interactions in nature and concluded that genetic diversity through gene-for-gene mechanisms that slowed the rate of disease progress was what prevented epidemics in the natural system. A similar natural system operates in black pine scale/pine (Edmunds and Alstadt) and in domesticated wheat/Hessian fly (Gallun) and such systems are now thought to be common in numerous arthropod and pathogen/plant interactions (Harris). For these systems at least, there are apparently dozens if not hundreds of genes available for resistance to a particular pest. That's the good news. The bad news is that the pest apparently has the capacity to express virulence to each and every resistance gene through a matching virulence gene based on current and very limited knowledge. This means the cycle of identifying resistance, incorporating it into a good agricultural plant, deploying that plant in farmers fields until an epidemic occurs and then repeating the process will continue unless some other approach is used.

Table 1. Agricultural disaster due to genetic homogeneity (partial list).

Potato Late Blight	Ireland	1840
Coffee Leaf Rust	Ceylon	1880
Grape Phylloxera	France	1884
Wheat Rust	U.S.A.	1916
Hessian Fly	U.S.A.	1920's
Bengal Rice Famine	India	1943
Sorghum Greenbug	U.S.A.	1968
Coffee Leaf Rust	South America	1970
So. Corn Leaf Blight	U.S.A.	1970

Such cycles are also familiar to agricultural scientists working with pesticides where chemicals are identified with pesticidal properties and developed and deployed in agricultural systems to control pests until populations develop that are no longer killed by the chemicals. Resistance to pesticides is also a genetically based characteristic manifested through different metabolic and behavioral aspects than those possessed by the susceptible population. The toxicologists do not fully understand pesticide resistance either, but there is an increasing belief among many scientists in HPR and Pesticide Toxicology that a fundamental understanding developed by one discipline for either HPR or pesticide resistance would contribute greatly to understanding in other disciplines. HPR specialists and toxicologists in Entomology, Plant Pathology and Agronomy need more interaction to examine cross-cutting issues and approaches.

Genetic engineers have developed the technology to move single genes from one organism to another, including transfers between species. There is at present virtually no information on the location of resistance genes currently operating in plants that would allow this new technology to be used as an alternative to conventional breeding. They can, however, transfer a small number of pesticidal genes from other sources, such as the endotoxin gene from *Bacillus thuringiensis*, into crop plants. This seminal breakthrough promises to revolutionize plant protection. However, the lepidopterous larvae that are the primary targets of this management approach have the capacity to develop resistance to the endotoxin, judging by experiments on *Heliothis*. The current state-of-the-art of Genetic Engineering allows incorporation of the gene throughout the plant where the endotoxin will be continuously expressed throughout the season. There is no significant doubt that if transgenic plants of, for example, cotton, are produced and deployed over wide areas that endotoxin resistance Heliothis will develop. This will essentially eliminate that strategy from being of further use with that gene.

Given the very limited arsenal of genes available for conferring resistance, development of transgenic tomato, tobacco, corn, etc. are also using essentially the same endotoxin gene. *Heliothis* also attacks these plants. If this powerful technology comes to be deployed simultaneously in numerous crops, the integrity of our agricultural system could be jeopardized when just *Heliothis* develops resistance to the endotoxin, let alone other Lepidoptera. Certainly, in the short term there will be pesticides available to back up this failure, and perhaps such a failure will provide a teachable moment for consideration of alternative strategies, strategies that could but probably won't be considered before this scenario has run its course.

For example, our purpose is to protect a human valued resource like cotton seed and fiber, tomato fruit, corn kernels, etc., not to kill insects or other pests willy nilly. Pests like *Heliothis* occur at specific times and places and attack specific tissues and must be present in significant numbers to threaten that human valued resource. The challenge is to prevent pests from reaching damaging levels with a log term sustainable strategy. The endotoxin gene remains effective as long as target pests populations are largely susceptible to the toxin in the above example. The present variables available are crop, seasonal time, and space, although hopefully methods will be developed to activate and deactivate resistant genes in specific plant tissues at specified times in the future.

Strategies that may keep endotoxin resistant insect populations from developing could include: 1) using the gene in small acreage dispersed cropping situations where immigration of susceptible populations overwhelm the capacity of indigenous insects to develop resistance, 2) using mixtures of transgenic and normal plants randomly dispersed together, 3) using transgenic plants in alternate year of longer time frames on a coordinated basis in a region, 4) using transgenic plants in latitudinal bands, perhaps on a rotating basis, and 5) stacking two or more resistant genes in a single plant or mixture or time or space deployment. These approaches would require a level of coordination not presently available but their use would slow or perhaps even prevent the development of resistance, especially if they could be combined with conventional HPR and pesticide based strategies. The headlong simultaneous deployment of a single resistant gene, whose vulnerability is demonstrated, in numerous crop species over a wide geographical area is destined to fail.

Whether such failure would be temporary and reversible or relatively permanent is unclear. Perhaps if no transgenic plants were grown for several or many seasons following an epidemic, the pest would return to a susceptible state comparable to that before the original deployment. Then, perhaps, one or more of the alternative strategies could be used to resurrect the technology in a sustainable fashion. Experience with pesticides and conventional HPR indicate widespread virulence erode slowly and rebounds quickly making retrofixes less effective than a conservative approach used from the onset.

Pests have demonstrated through their genetic diversity an impressive ability to withstand pesticides, conventional HPR and, now, genetic engineering. The latter is an exciting tool but we need to know much more about all aspects of plant/pest interactions if we are to bring the litany of agricultural disasters in Table 1 to an end. Knowledge of the ecology and population biologies of pests must be enhanced and combined with knowledge of molecular biology, genetics, and metabolism of pests and plants for our agroecosystems to be manageable in a reliable and productive manner.

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Feature

Development of the Economics Associated with Resistance

Recently A. L. Knight and G. W. Norton published a review titled "Economics of Agricultural Pesticide Resistance in Arthropods". Their review focuses on the economics of resistance at the farm and aggregate levels. The nature of resistance impacts is discussed, followed by a review of the economic theory used to analyze the impacts. Their review concludes with a discussion of the implications for resistance management, public policy, and future research.

According to Knight and Norton, modern economic analysis of pesticide resistance began in the early 1970's with the development of conceptual optimization models. With increased computer capabilities, a number of optimizing economic models which address the dynamic nature of resistance have followed (see Table 1). Unfortunately, the utility of these models has been hampered by the lack of appropriate biological and production data required for econometric analysis.

In a recent econometric analysis of resistance in cotton, Harper (1986) points to the difficulty in performing a meaningful analysis due to the lack of appropriate data for model calibration. This is disturbing given that cotton is one of the most studied crop/pest complexes in agriculture, and one with a history of severe resistance problems. The recent work of Harper (1986) and Archibald (1985), in examining the micro-economic impacts of resistance for cotton production in the Imperial Valley of California, however represents the most thorough treatment of a single corp to date. For reasons outlined above, both approaches are highly theoretical, but given the appropriate data they serve as a model for an exhaustive case study approach.

Given the current situation with regards to evaluating the economic impact of resistance, priority should be given to the development of the appropriate biological and productivity data for econometric analysis. In developing the appropriate biological data, emphasis must be placed on improved methods of detecting and monitoring resistance. In addition, field studies must be designed or evaluated with consideration for economic analysis. With regards to data requirements for econometric analysis, both Harper (1986) and Archibald (1985) stress the importance of multi-year analysis. Due to the dynamic nature of resistance, it is essential that a time-horizon of several years be employed to assess any economic benefit from preserving pest susceptibility.

A third problem the economist must deal with is separating out the influence of resistance form all other factors that influence crop yield and/or quality. For example, Archibald (1985), in evaluating the impact of resistance on yield among different cotton farming operations in the Imperial Valley of California, considered the influence of the following aspects of production:

- Years of farming experience
- Purchased pest control information
- Use of IPM (pheromones and biological control)
- Land quality index
- Water management practices
- Fertilizer use
- Cultivation and harvest practices

Assessing these factors can best be accomplished through controlled field trials. Analysis of all crop production factors relative to resistance is crucial for a regional econometric analysis of resistance in production agriculture.

Based on the amount of resistance research that has been conducted in cotton, this crop/pest complex would appear to be a likely candidate for directed field research to develop the necessary data for econometric analysis. Other crop/pest complexes in which the case study approach may be best applied are for the Colorado potato beetle in the eastern United States, Pear Psylla in the western United States, and spider mite worldwide. Another source of data is from chemical company field trials. In addition to developing product efficacy data, these field trials could be used to track resistance development. Another source of information that may be useful in an econometric analysis of the impact of resistance is historical records of pesticide use. Harper (1986) suggests a retrospective analysis of Cooperative Extension spray recommendations as a means of inferring resistance. A trend in the recommendation of increased application rates, or the number of applications per season, or alternate chemicals in case of control failure could be used to infer a resistance problem. Obviously such an analysis must take into account other crop production factors in estimating the economic impact of resistance. Analysis of individual farm records of pesticide use may also offer some insight into the development or resistance, however these records are generally not available. Only a few states, such as California and New Hampshire require record keeping of farm pesticide use. In both cases, accompanying yield or crop value information would also be necessary to make the simplest economic assessment.

The economics of resistance should be an important factor in formulating public policy, developing pesticide resistance management strategies, and in directing the research necessary for their effective implementation. Consideration must be given for developing a stronger case for the economic impact of resistance. This should include large scale field trials and/or regional studies which employ "state of the art" resistance monitoring methodology and collection of concurrent crop yield/quality data. Only then can a more robust analysis of the economic impacts of resistance be considered.

Table 1. Pesticide Resistance Econometric Models

Hueth & Regev (1974)	First published economic model to include. resistance. Optimizes marginal profits.
Carlson (1977)	Use of kill function to indicate resistance over 5 year period.
Lazarus & Dixon (1984)	Simulation model compares profits for a single farm vs collective regional action to minimize resistance.
Plant, Mangel & Flynn (1985)	Dynamic optimization model. Demonstrates optimal timing of spray to manage resistance.
Archibald (1985)	Dynamic programming model used to determine optimal input use given resistance under alternative regulatory policy and IPM strategies over 10 year period.
Lichtenberg & Zilberman (1986)	Specifies pest control function distinct from other cost functions. Includes increasing pesticide usage as resistance develops.
Miranowski & Carlson (1986)	Optimal utilization of pest susceptibility over time.
Harper (1986)	Dynamic simulation model. Use of pesticide mixture to delay resistance over 5 & 10 year periods. Cost of pesticide adverse health effects considered.

References:

Archibald, S. O. 1984. A dynamic analysis of production externalities: Pesticide resistance in California cotton. Ph.D. thesis. Univ. of California, Davis, 325 pp.

Carlson, G. A. 1977. Long-run productivity of insecticides. Am. J. Agric. Econ. 59:543-48.

Harper, C. R. 1986. Optimal regulation of agricultural pesticides: A case study of Chlordimeform in the Imperial Valley. Ph.D. thesis. Univ. of California, Berkeley. 148 pp.

Hueth, D., Regev, U. 1974. Optimal agricultural pest management with increasing pest resistance. Am. J. Agric. Econ. 56:543-52.

Knight, A. L. and G. W. Norton. 1989. Economics of agricultural pesticide resistance in arthropods. Ann. Rev. Entomol. 34:293-313.

Lazarus, W. F., Dixon, B. F. 1984. Agricultural pests as common property; control of the corn rootworm. Am. J. Agric. Econ. 66:456-65.

Lichtenburg, E., Zilberman, D. 1986. The econometrics of damage control: Why specification matters. Am. J. Agric. Econ. 68:261-73.

Miranowski, J. A., Carlson, G. A. Economic issues in public and private approaches to preserving pest susceptibility. In: Pesticide Resistance: Strategies and Tactics for Management. pp 436-48.

Knight, A. L., Norton, G. W. Economics of agricultural pesticide resistance in arthropods. Ann. Rev. of Entomol. (In press).

Plant, R. E., Mangel, M., Flynn, L. E. 1985. Multi-seasonal management of an agricultural pest II: The economic optimization problem. J. Environ. Econ. Mgmt. 12:45-61.

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New/Reviews:

ISPP Chemical Control Committee organized workshop on fungicide resistance in Ivory Coast, Africa

The Chemical Control Committee in cooperation with FAO and the Fungicide Resistance Action Committee (FRAC) of the International Group of National Associations of Agricultural Manufacturers (GIFAP) held this workshop for west Africa in Abidjan, Ivory Coast 19-25 February 1989, which was attended by more than 50 participants mostly from west African countries.

Lecturers were K.J. Brent (UK), J. Dekker (Netherlands), C.J. Delp (USA), J.W. Eckert (USA), S.G. Georgopoulos (Greece), F.J. Schwinn (Switzerland), and M.A. de Waard (Netherlands). The workshop was organized by C.J. Delp (USA) and C.P. Bah (director of the Ecole Nationale Superieure Agronomique [ENSA] at Abidjan).

This was the fifth in a series since 1984; earlier workshops were held at Kuala Lumpur for southeast Asia, San Jose for Mid-America and the Caribbean, Santiago for South America, and Nairobi and Mbita Point for east Africa.

ISPP Newsletter
April, 1989, page 2.

Dow Chemical Introduces Cockroach Resistance Management Program

Field strains of German cockroaches have begun to show signs of resistance to pyrethroids. Concerns are also increasing regarding existing and potential resistance to some of the other chemical classes utilized by the structural pest control industry. Recognizing that the structural pest control industry was as vulnerable to pyrethroid resistance as the cotton and cattle industries the Dow Chemical Company decided to mount a resistance management campaign designed to inform and educate its customers on how to best manage the prevention of resistance in German cockroaches.

The pest control industry has relatively few insecticides registered to use on German cockroaches with fewer new products in development. It is important that these chemicals be preserved so that their effectiveness will be extended as long as possible. For this reason, Dow has named their resistance management strategy the "*Consistent Insect Control Program*".

A team of Dow research and marketing officials decided on an approach that involves supporting university research investigating German cockroach resistance as well as educating the pest control industry concerning the facts about resistance. This education includes disseminating information regarding the genetic aspects and mechanisms of resistance as well as effective and appropriate rotational procedures to manage the problem.

The team initially created a slide presentation that explained the resistance problem, discussed the genetics and examined various methodologies used to combat resistance. They then made and distributed several video versions of the slide story. In addition, a 16-minute color video entitled "*The War Against Resistance*" was produced by Dow. This video includes interviews with Dr. George Georghiou, Dr. Michael Rust and Dr. Donald Reierson of the University of California, Riverside and Dr. Donald Cochran of Virginia Technological Institute and State University. The four entomologists each discussed and illustrated their own research on resistance as well as their recommendations for ways to avoid cockroach resistance.

A magazine supplement, entitled "*Rotation Management - Your Key to Consistent Insect Control*" was developed and published in the February, 1989 edition of Pest Control Magazine.

Utilizing the videos, articles and magazine supplements, Dow technical and sales representatives are now introducing the resistance management concept to the pest control industry in both one-on-one and group presentations. These presentations include specific recommendations on how to rotate between pyrethroid and organophosphate insecticides for German cockroach control.

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International Pest Resistance Management Congress, November, 1991.

An international organization to help implement pest resistance management is on the drawing board. This will involve working groups to develop recommendations for adoption by the U.S. Congress in 1991. Membership on the working groups and attendance at the Congress will be by invitation. The planners are now soliciting nominations, ideas, help and financial support from a broad base.

The Congress will identify practical approaches to encourage and coordinate the implementation of local resistance management programs on an international scale. This will be accomplished by bringing together key public and private sector individuals to foster institutional policy, organization and action programs. An international management group will be organized to ensure proper follow-up for the Congressional recommendations and continuation of coordinated activity.

The Agricultural Research Institute has agreed to host the first "*International Pest Resistance Management Congress for Implementation*" that will be held at the National Academy of Sciences in Washington, D.C. Support is coming from government, industry and foundations. The twenty member Host Nation Planning Committee represents academic, environment, government, and industry interests, and will involve broad international participation. Both scientists and policy makers at senior decision-making levels will be invited to the Congress.

Working groups on disease, insect, and weed control, as well as communications, implementation constraints and congressional charter will prepare options and recommendations on specific issues during 1990-91 Congress. For additional information write to:

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PEG-US Update : 1989 Research and Monitoring Program

During 1989, the industry group PEG-US (Pyrethroids Efficacy Group in the U. S.) will continue to help coordinate the beltwide *Helithis virescens* monitoring program with state research and extension personnel across the U.S. cotton belt. During 1988, collaboration between industry and universities in the adult monitoring program resulted in the testing of over 60,000 moths (590 tests). This effort has provided valuable information on both the geographic and seasonal variation in susceptibility in *H. virescens* adults to the pyrethroids. During 1989, we plan to continue this effort.

However, the relationship between these monitoring results and actual control in the field still is not clearly understood. This is further complicated by the fact that monitoring results are obtained on the adult while field applications are directed at the larval stage. An understanding of this relationship is critical if we hope to be able to predict and confirm resistance-induced control problems and recommend specific control strategies.

PEG-US has designed a field research project to attempt to clarify this issue. The project will be conducted by Dr. Jerry Graves and Steve Micinski of Louisiana State University and Drs. Randy Luttrell and Bob Head of Mississippi State University. Figure 1 describes the project. The overall goals of the project are:

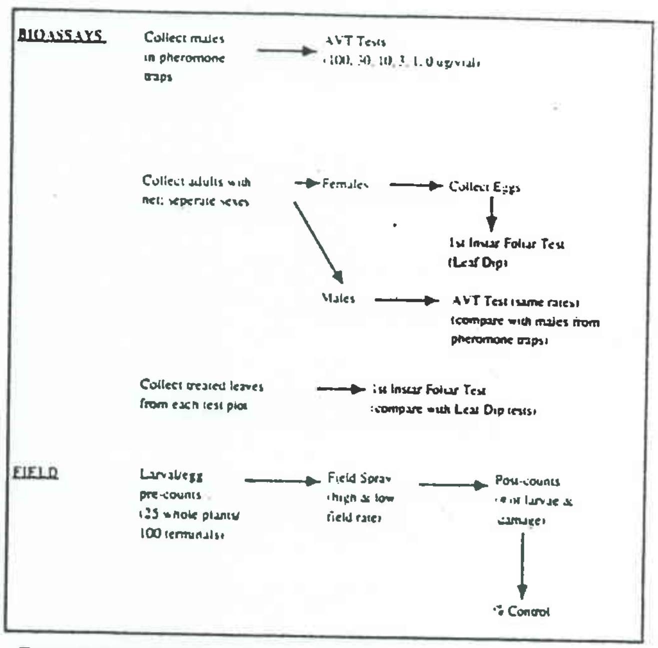

Figure 1: 1989 PEG-US/University Field Research Program Test Flow

- To relate the results of the monitoring bioassays to field control,
- To develop a better understanding of the relationship between the 1st instar foliar test and the adult vial test (AVT),
- To determine a discriminating dose for the 1st instar foliar test, and
- To begin on the development of a model to predict resistance control problems in the field.

Drs. Steven L. Riley, IanWatkinson, E.I. Du Pont & Co.; Chuck Staetz, FMC Corp.; James Whitehead, Hoechst-Roussel; Harlan Feese & David Ross, ICI Americas; Walt Mullins & Don Simonet, Mobay Corp.

NATIONAL IPM SYMPOSIUM LAS VEGAS, NV : APRIL 25-28, 1989

MANAGING RESISTANCE TO PESTICIDE IN IPM SYSTEMS

Pesticides are fundamental components of many, if not most, IPM programs. Registration costs of new and existing products, environmental and regulatory concerns and the slow rate of discovery of novel control agents all restrict new product introductions, and, therein, make it increasingly more critical to manage the use of existing products. A decreasing number of IPM-compatible pesticides and loss of materials due to resistance threaten the continuity of many IPM programs.

Workshop participants were pleased that the National IPM Coordinating Committee recognized the important role of resistance management in IPM by designating a workshop to address this issue. Unfortunately, the consensus was that most state IPM programs do not, at present, incorporate resistance management objectives into the overall tactics of integrated management.

Recognition was given to the fundamental fact that good multi-tactic integrated management, resulting in optimum utilization of non-chemical control tactics, is the most effective overall resistance management strategy. The objective of our workshop was to summarize what there is to show for implementable resistance management and to highlight the research that should be conducted by IPM programs to achieve implementation of specific resistance management tactics within the next 3-5 years.

Topics for discussion were divided into two groups: one involving sectors of individuals or groups involved in the management of resistance (experimental station research & extension, state IPM programs, agrichemical industry, private consultants, growers and commodity groups), and the other involving tactics that are cited as important for managing resistance.

Sectors

1. What is the majority opinion of leaders in your sector regarding the most important and practical research that needs to be done in the coming 5 years in order to advance implementation of resistance management in IPM programs?

- Bioassay development and validation work to relate bioassay results to the field performance of products is critically needed.
- Establishment of programs to detect base-line susceptibility levels for new products and programs to monitor susceptibility to current products.
- Field validation of resistance management tactics.
- Characterization of cross-resistance, multiple resistance, and synergism phenomena as they relate to implementing resistance management strategies.

2. What sort of coordinating activities between sectors would facilitate implementation of resistance management?

- Establish Resistance Management Working Groups, composed of representatives from each major sector. These working groups should be given the following charges:
- Target the most critical pest/chemical complexes to which resistance is posing an immediate threat to the specific IPM program.
- Identify the most critical research needs for implementation of resistance management in that commodity.
- Generate political and financial support for conducting implementation research on resistance in the specific commodity.
- Elect a representative to interact with other such commodity resistance workgroups in order to coordinate resistance implementation efforts on a national level and to maintain liaison with ARS and ESCOP on resistance related implementation research.

Tactics

1. How practical are resistance monitoring programs? Who should sustain them once the research stage is finished?

As already mentioned, monitoring programs were cited as very important for implementation of resistance management. Yet, major problems were cited regarding who should maintain such programs. Some university representatives felt that monitoring could not be sustained by university-based programs given the existing tenure review systems, liability issues, and the funding situations. The consensus was that the Commodity Resistance Workgroups should resolve this issue on a case-by-case basis.

2. How practical is resistance risk assessment? What is the reliability of this approach? Is it equally applicable to insecticides, acaricides, fungicides, and herbicides?

The consensus was that no reliable, systematic, formal procedure for assessing the risk of resistancedevelopment (to new classes of control agents) is presently available. Marked recent examples were cited where risk-assessment criteria either predicted resistance much too early or failed to predict resistance when it did occur to new control agents. However, because of the economic consequences of resistance, industry is now taking the initiative, on a case-by-case basis, to consider the risk of resistance to new control agents prior to their introduction into the marketplace. In some cases this has resulted in label restrictions on the use of new products.

3. Are we ready to establish chemical use strategies based on rotations or alternations? Is the value of rotations versus alternations different for management of resistance to insecticides versus fungicides or herbicides?How does the value of rotations and alternations differ for new chemicals for which resistance is not known to exist, versus older chemicals for which resistance is known to exist?

The value of rotations versus mixtures of new products is controversial. In the majority of cases, barring the existence of specific data which would support the use of mixtures, it is recommended that the use of mixtures be minimized. Essentially no conclusive field data can be cited to support or reject the use of either mixtures or rotations. However, the modelling of this situation indicates that there are only limited circumstances under which mixtures are advantageous over rotations. Conversely, the cost of wrongly using mixtures is the development of multiple resistance.

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Southern States Meeting on Soybean Looper Resistance

A meetings was held at Biloxi, Mississippi, April 13-14, 1989, to discuss the increasing problem of pyrethroid resistance in the soybean looper (*Pseudoplusia includens*). Attending the meetings were entomologists from Alabama, Louisiana, and Mississippi, as well as representatives from the chemical companies DuPont, FMC, Hoechst Roussel, ICI, Rhone-Poulenc, and Valent, and the biological company Abbott. The pest is now causing defoliation of soybean in parts of a number of southern states, in spite of insecticide applications at recommended rates. Methomyl resistance had been reported in Alabama (Chiu and Bass 1978), but pyrethroid resistance was demonstrated in the soybean looper for the first time in Mississippi in 1987 (Felland et al 1989).

In all three states, most of the control failures occurred in regions of intensive cotton-growing; in adjacent areas without cotton, pyrethroid control of the soybean looper was usually successful. Soybean loopers are fairly common in cotton, though rarely cause much damage to this corp; thus it is likely that loopers sprayed on cotton in June and July evolve resistance and in succeeding generations move to soybean where they may be difficult to control (reviewed by Felland el al, 1989). Another possibility is that loopers, which are not thought to overwinter in the region, are exposed to pyrethroids while feeding on winter vegetable crops in Florida or Mexico; subsequently they migrate north and infest soybean, where control failures may again result. Interactions between these two factors may be important, but the correlation of soybean infestation with cotton production shows that cotton has an important effect. In contrast, the effect of winter hosts still lacks documentation.

Insecticide company spokesmen admitted that the problem existed, but pointed out the need to ensure that control failures actually resulted from pyrethroid resistance rather than poor application or inclement weather. Some researchers agreed that application can affect control, and suggested that the economic threshold be applied to smaller and more susceptible larvae, though others suggested this might mean applying insecticides when they are not needed. A control failure with 0.1 lb A.I./acre of permethrin was described in Northern Florida; only 50% control was achieved. When permethrin was again applied at 0.2 lb/acre (Ambush and Pounce are registered for this rate) using an ultra-low volume oil-based spray for uniform coverage, 83% control resulted. Thus adequate control might still be possible (though expensive) even in an area where a standard dose has failed. Almost everyone admitted that there are no good alternatives to pyrethroids currently on the market, although insecticides such as Bacillus thuringiensis (Dipel) diflubenzuron (Dimilin), and thiodicarb (Larvin) might be useful if pyrethroids become ineffective.

The organizers had hoped that the meeting would result in an area-wide resistance management plan, in the same way that entomologists and industry representatives had formulated a management plan for the tobacco budworm on cotton in 1986. However, some felt that little could be done on soybean to manage looper resistance, especially since the problem may be largely due to insecticide use on cotton. Soybean loopers typically receive one treatment, if any, per year, unlike the situation in cotton, so that within-season rotations of insecticides are recommended by cotton entomologists would not be possible to soybean. There was also some disagreement over what was actually known about the movements and overwintering habits of the soybean looper. Better knowledge of looper biology will inform us whether resistance can carry over from year to year within a local area, whether more southerly regions are the source of the resistance problem, and whether resistance management can be feasible.

In the end, no resistance management plan was agreed. Nonetheless, the meeting was a useful exchange of information, and important areas of future research were identified. The meeting also provided convincing evidence of a number of area-wide trends - the existence of resistance, and the association of resistance with cotton, for example - that would have seemed less worrying if documented in one state alone.

Resistance in mosquitoes has often been blamed on agriculture, but here is an example where resistance on one crop is almost certainly caused by insecticide use on another crop. Overuse of insecticides in agriculture will have hidden costs; among them may be insecticide resistance on crops quite different from those that are most heavily sprayed.

Abstracts of the papers presented at the meeting have been collated by Jim Hamer (Department of Entomology, Drawer EM, Mississippi State, MS 39762), from whom copies can be obtained.

Chiu, P. S.-B and Bass, M. H. 1978. Soybean looper: Minimum rates of insecticides for control. J. Entomol. Soc. 13:155-160.

Felland, C. M., Pitre, H. N., Luttrell, R. G., and Hamer, J. L. 1989. Resistance to pyrethroid insecticides in soybean looper (Lepidoptera: Noctuidae) in Mississippi. J. Econ. Ent. (in press).

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ESCOP Resistance Brochure

behavior phenomena, provides an accelerated means of evolutionary selection. Experimentation has revealed several related phenomena, including:

- Selective pressure from subnematicidal exposures can result in populations with a lower fitness of reproduction;
- Selected and/or conditioned nematodes can be more sensitive to nematicidal doses;
- Resistant populations with indifferences to nematicidal doses;
- Resistant populations that show higher reproductive fitness;
- Development of cross susceptible and cross resistant populations;
- Development of populations that show an habituation to nematicides;
- That real differences between nematode species are maintained in their response to nematicides.

These aspects are evident in the illustration (Figure 1) which represents a simplified summary of the results. Although these nematicides are presumed to function with the same mode of action, different species of nematodes clearly respond differently.

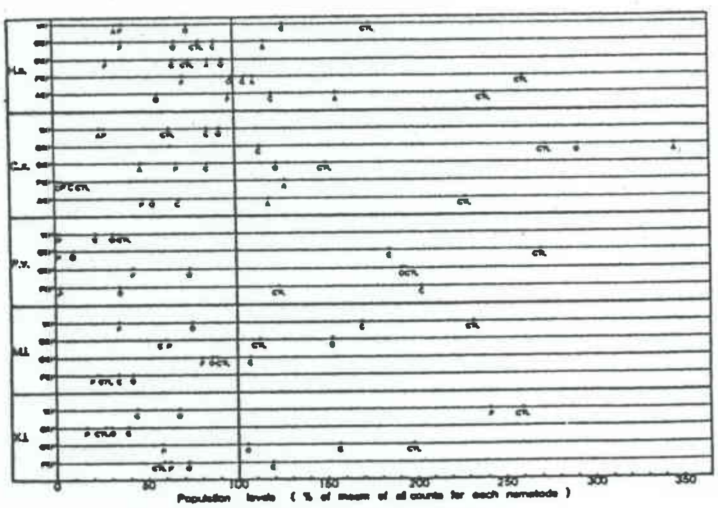

Figure 1. Population levels as percent of overall mean for each nematode in treatments with different nematicides at sublethal levels. A = Aldicarb, O = oxamyl, C = carbofuran, P = Fenamiphos, CTL - control, = no treatment, WP = wild untreated population, CSP = carbofuran stressed population, OSP = oxamyl stressed population, PSP = fenamiphos stressed population, ASP = aldicarb stressed population, H.s. = Heterodera schachtii, C.x. = Criconemella xenoplax, P.v. = Pratylenchus vulnus, M.i. = Meloidogyne incognita, X.i. = Xiphinema index.

It is significant that when the well adapted population is de-stressed, i.e., allowed to reproduce in the absence of stressing pesticides, the population response to nematicidal doses is modestly, if at all, changed from that of stressed populations. A series of *in vitro* experiments seeking to assess the immediate capacity (24 hours) of nematodes from populations of varied history to cope with immersion in high concentrations of nematicides, revealed as varied a range of responses as those with greenhouse trials. In many cases the findings supported the results obtained with longer term greenhouse trials, but in many other cases, response differences surfaced that revealed the presence of confounding factors of short-term importance that could not be seen in the long-term experiments. In both greenhouse and *in vitro* trials, the responses were a function of the nematode species, preconditioning, and the nematicide treatment. Moreover in a trial utilizing preconditioned nematodes of one species on different hosts, population structure differences were observed. Whereas with one host the second and third larval stages predominated, on the second host the fourth and adult stage predominated.

In the normal situation, the applied nematologist is primarily concerned with the pestiferous nematode and the host; however, the soil microfloral component must not be ignored. Greenhouse trials have shown that a microfloral component can be a confounding factor. Pesticide stressing of the appropriate microfloral species, but not all microfloral species, effects a population better able to degrade the pesticide. This has been demonstrated not only in greenhouse trials, but also in field soil studies from banana plantations of Central America. Field studies have also been consistent with the observations of adaptive responses demonstrated in greenhouse and *in vitro* trials, in that nematode populations in plots receiving repeated nematicide treatments are usually higher than those in control plots.

In conclusion, these pesticide studies suggest that the consequences of pesticide treatment for nematode control is dependent upon a) the nematode species, b) the host species, c) the soil microfloral component, and d) the properties of the nematicide. Ignoring one or more of these factors or a misguided use of a sequence of different nematicides can lead to a more intractable nematode pest problem. The ease with which nematodes can adapt to stress is an indication that in all probability nematodes will be able to utilize these same natural processes to quickly overcome alternative nematode management practices including single gene based plant resistance and biocontrol agents. A more extensive overview will be published in *Revue de Nematologie* later in 1989.

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Pyrethroid Resistance in Colorado Potato Beetle: Minnesota-North Dakota

Pyrethroid insecticides were first available in 1981 to potato growers in the Red River Valley of Minnesota and North Dakota. By 1982, fenvalerate (Pydrin™) was the insecticide of choice, for control of Colorado potato beetle (CPB). In the early 1980s, CPB was usually not abundant enough to cause economic loss, but it became standard practice to spray at least once for CPB, and many growers treated more than once. Resulting control of CPB was outstanding, but over the next several years need for treatment became much greater as CPB population pressure increased. First reports of possible resistance problems came to our attention in 1985. In one instance, a grower near Karlstad, MN, reported control failure with permethrin (Ambush™).

In 1985, we initiated a program of laboratory testing to monitor pyrethroid resistance in adult beetles from various Minnesota-North Dakota locations. We found that CPB from all locations sampled, had appreciably elevated levels of resistance to both fenvalerate and permethrin. LD50s ranged from 5.1 to 15.9 g per beetle for fenvalerate and from 3.5 to 10.2 g per beetle for permethrin except the Karlstad population which had an LD50 of 31.9 g per beetle for permethrin.

For CPB never previously exposed to pyrethroid insecticides, Forgash (1985) reported an LD50 of 0.12 g per beetle for fenvalerate and LD50 of 0.23 g per beetle for permethrin. In 1982, we had tested pyrethroid naive beetles from Glyndon, MN, and determined the LD50 to be 0.17 g per beetle for fenvalerate, but we did not test permethrin.

One of the most resistant populations we have tested from the Red River Valley is that from the University of Minnesota Experiment Station in Crookston (Table 1). In 1985, the LD50 for 1st summer generation adults was 5.7 g (micrograms) per beetle in 1985 (resistance ratio 33.5 compared to our 1982 baseline), 15.2 g per beetle in 1986 (resistance ratio 89.4), and 39.8 g per beetle in 1987 (resistance ratio 234), and annual rate of increase of 3 fold since 1982.

Table 1. Resistance to fenvalerate in 1st summer generation Colorado potato beetles, Minnesota-North Dakota, 1982-88

Year	Glyndon	Crookston	Grand Forks
1982	0.17	-	-
1985	-	5.71	9.70
1986	-	15.19	11.93
1987	-	39.80	14.09
1988	-	38.74	23.70

Baseline LD50 for fenvalerate = 0.17 g/beetle (Glyndon, MN,). LD50s are assumed to have been identical for the 3 populations in 1982.

In 1988 we controlled CPB at the Crookston station without the use of pyrethroid insecticides. Against 1st generation larvae we applied one spray of *Bacillus thuringiensis* var. *san diego* (M-One™) with methyl parathion (Pencap-M™) and one spray of oxamyl (Vydate™). First summer generations CPB adults at Crookston had an LD50 for fenvalerate of 38.7 g per beetle (essentially identical to that of 1987). In contrast, at the Red River Valley Potato Growers Association Research Farm, Grand Forks, ND, where fenvalerate was applied routinely both years, the LD50 for 1st summer generation adults was 14.1 g per beetle in 1987, and 23.7 g per beetle in 1988. We could not collect enough 2nd generation adults at Crookston to test, but the LD50 for fenvalerate on 2nd generation adults at Grand Forks was 87.5 g per beetle (resistance ratio 514).

In Minnesota and North Dakota, CPB populations from different locations vary considerably in resistance to fenvalerate (Figure 1). In 1988, the LD50 for fenvalerate in 1st generation CPB was 10.2 g at the University of Minnesota Experiment Field, Becker, on the irrigated sands of east central Minnesota, and 5.0 g at the University of Minnesota Experiment Station, Rosemount, where potatoes are not grown commercially. At all location, the slope of the line plotting mortality against dosage is relatively flat indicating that individuals within the population differ greatly in resistance.

Most overwintering beetles in our area are 2nd summer generation adults, but it is probable that at least some 1st summer generation beetles also overwinter. The shift to bivoltinism is recent in Minnesota and North Dakota. Literature from the 1960s describes CPB in our area as univoltine and apparently it still is in Manitoba. We find that overwinterd beetles are appreciably more susceptible than were the same beetles upon emergence the previous summer (Figure 2). This observation would seem to suggest that it might be advisable to target control against overwintered adults before oviposition occurs. However, we do not recomend this for two reasons: 1) because overwintering

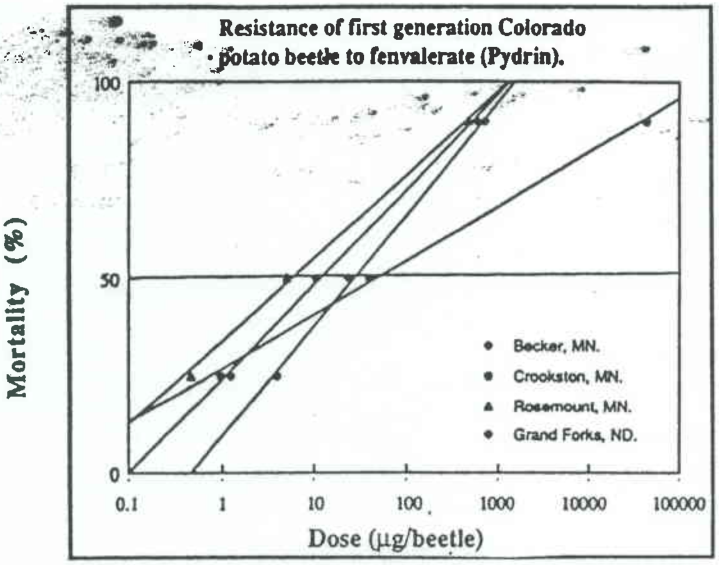

Figure 1. Resistance of 1st generation CPB to fenvalerate (Pydrin)

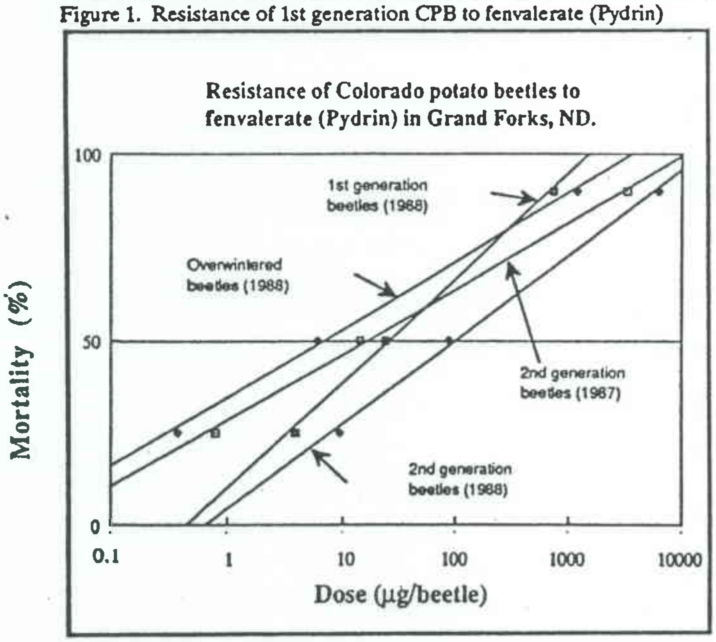

Figure 2. Resistance of Colorado potato beetle to fevalerate (Pydrin), Grand Forks, ND

beetle numbers in our area are almost subeconomic, and 2) because it is our recommendation that pyrethroids not be applied more than once a season. Since larvae are much more susceptible than adults, it still seems preferable to apply that one pyrethroid treatment when 1st generation larvae are present.

From our observations, it appears that field control of CPB becomes a problem when resistance rations to pyrethroid insecticides are much above 100X. Forgash (1985) classified beetles with resistance ratios above 30X as highly resistant. The difference may be that in our situation control is targeted almost entirely against larvae, whereas on the east coast control of overwintering is necessary.

We also determined LD50s for a number of candidate pyrethroids and found that cross-resistance extended to these chemicals as well. We did this by comparing LD50s for these candidate insecticides against fenvalerate-resistant populations from Minnesota and against relatively fenvalerate-susceptible beetles from Idaho. This does not bode well for the future of pyrethroid insecticides for CPB control.

Reference:

Forgash, A. J. 1985, Insecticide resistance in Colorado potato beetle. 1985. IN D. N. Ferro and R. V. Voss, (eds.) *Proc. of the Symposium on the Colorado Potato Beetle,* XVIIth Intern. Congr. Entomol. Res. Bull. No. 704, Mass, Agric. Exp. Sta., pp. 33-52.

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Status of Pathogens Resistant to Fungicides in California

Pathogens developing resistance to fungicides have emerged in California's agriculture crops yet experience of major crop losses have been minor. California grown crops are exposed to less disease pressure and do not require as many fungicide applications per season for effective disease control than crops produced in many other areas of the world. The California climate can be described as semi-arid in the central valley with little rainfall from late spring to early fall and cool and moist but not rainy in the coastal areas near the Pacific Ocean. Examples of resistant problems reported from California are antibiotic (streptomycin) resistance in *Erwinia amylovora*; benzimidazole resistance in *Monilinia* spp., *Botrytis cinerea*, and *Penicillium* spp.; dicarboximide resistance in *Botrytis cinerea*; biphenyl resistance in *Penicillium* spp.; and demathylation inhibitor (triadimefon) resistance in *Uncinula necator*. Problems of resistance have not developed in California for such fungicides as dodine, metalaxyl, and triforine though crop losses have been experienced with product use in crop production areas outside California. Other examples of fungicides for which field resistance has not been detected under usage patterns in California are the sulfurs, coppers, dithiocarbamates, imidazolines, and guanidines.

Resistance Management Newsletter

Resistance Event Survey

Date: ____________________

Name: ____________________

Street: ____________________

City, State: ____________ Zip ______

Phone: ____________________

Pest Type (Please check the appropriate set of resistance features and include any comments you would like to make.)

( ) Insect ( ) Disease ( ) Nematode ( ) Weed

Crop(s)

Occurrence Distribution

( ) Regional (Multi-State or Province)

( ) County Wide

( ) Township

( ) Fields

( ) One Field or Plot

Resistance Type:	Comment
Pesticide(s)	
Host Plant Resistance Gene:	

Basis of Resistance Determination:	Comment
Field Failure ( )	
Discriminating Dosage ( )	
Biochemical Bioassay ( )	
Other Assay ( )	

Thus minimal numbers of fungicide applications made on crops in California have placed less pressure for pathogen selection towards resistant strains. This explains why field-resistance to fungicides are not likely to be reported first from California, with exceptions on some specialty crops grown in this state. Also, California, growers are not likely to use only one class of fungicide for control of a specific disease throughout the growing season because of the variations in disease pressure on crops. Recommendations have emphasized the use fungicides based on needs for disease control on individual farms. Such decisions are essential because of the diversified farming of over 200 crops plus numerous cultivars which vary in disease susceptibility. Furthermore, disease control recommendations are made largely by consultants and are based on current integrated pest management procedures developed by the various research agencies. Thus, in many instances when only a few application of fungicides are made. Losses resulting from fungicide resistance could be attributed to poor management strategies or lack of basic information on proper use of fungicides and are typically localized.

However, widespread disease control failures have been observed with the use of triadimefon against grapevine powdery mildew in California. During the years between 1982 and 1986, triadimefon was used exclusively for powdery mildew control on large grapevine acreages throughout California. Three applications per year were made initially (1982-1984) but because of the increased disease pressure and reduced efficacy in 1985 and 1986, the number of applications was increased to as many as nine per year in some coastal production areas. Investigation revealed that much of the problem could be attributed to application practices and one in particular stood out as the primary factor in reduced efficacy, namely applications were initiated much too late in the spring. Though growers were following the label recommendations, it is now known that in some years in California the powdery mildew epidemic is well underway by the time of first triadimefon application. This type of control program (eradication) placed increased selection pressure on the pathogen and resulted in decreased sensitivity to triadimefon in populations of U. necator in California. Earlier application and shortened intervals between applications has allowed the continued, effective use of triadimefon against grapevine powdery mildew.

Research strategies required for delaying or preventing resistance in pathogens to fungicides are: 1) application based on a forecasting system instead of the concept of protection insurance; 2) prevention of continuous exposure of pathogens to a single fungicide by alternating with other fungicides with different modes of action; 3) monitoring the pathogen for resistance to fungicides to prevent buildup of high populations which could trigger crop failures; and 4) introduction of other control measures such as cultivar resistance, biological control, fungicides with negative cross-resistance, and cultural manipulations.

Much of today's research funding has not properly addressed strategies for solving field resistance problems in pathogens to fungicides but have been directed at Integrated Pest Management (IPM) and non-fungicide alternatives for disease control. These efforts are progressing well but have had little relevance to insuring continued effectiveness of fungicides and their uses are essential to retaining their efficacy and without such research, resistance problems on the few fungicides available could eliminate them from our arsenal of control measures. This could result in serious disease epidemics in California and hamper our ability to produce profitable crops of high quality. California agriculture is dependent and will undoubtedly remain dependent on fungicides for control of plant diseases for generations to come. Effective use of fungicides directly impacts the prevention and delay in development of fungicide-resistant strains of pathogens.

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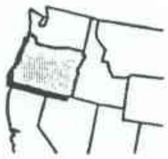
Genetic Improvement of a Natural Enemy

A predaceous mite, *Ambylseius andersoni* Chant, which is highly resistant to organophosphates and carbamates has been imported from its area of origin (Verona, Italy), and is being reared in our laboratory with a view towards incorporating it into mite management programs where these insecticides are used for the control of other insect pests.

Hybridization experiments have shown that the imported species, is conspecific with *A. potentillae* Garman, which has been shown to be an effective predator of *Panonychus ulmi* on apple in the Netherlands. In Italy, *A. andersoni* has been used in mite management on apples, peaches, and grapes.

Slide-dip bioassays show that the imported population has approximately 100-fold higher resistance to azinphosmethyl than the native population of *A. andersoni*. High resistance levels have also been confirmed for malathion, phosalone, diazinon, and carbaryl. The mode of inheritance is currently being investigated, as is the response to low levels of relative humidity, a factor thought to be limiting in the geographic distribution of this species.



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Pear Psylla Resistance in the Northwest U.S.

A group of seven entomologists from three western states and British Columbia have cooperated for the second year in carrying out a regional pyrethroid resistance survey for *Psylla pyricola* Foerster in pear orchards of western North America. This pest has previously developed resistance to almost every compound used for its control.

In 1988, fenvalerate resistance was monitored at 51 sites in California, Oregon, Washington, and British Columbia. A slide-dip bioassay was used on post-diapause overwintering adults, collected in pear orchards before prebloom pyrethroid sprays were applied.

Resistance levels ranged from highly susceptible in an isolated experimental orchard on the Oregon State University campus in the Willamette Valley, to 152-fold resistance in central Washington (Fig. 1). Highest resistance levels occurred in the Wenatchee and Yakima regions in Washington, which are among the largest contiguous areas of pear production in North America. Even organic and low-spray orchards showed over 20-fold resistance, indicating that it is an area-wide phenomenon.

Moderate levels of resistance (10-30 fold) occurred in northern Washington, where orchards are somewhat more isolated and pyrethroid use has been less intense; and in British Columbia, where selection primarily with permethrin has conferred cross-resistance to fenvalerate. In the Hood River Valley of Oregon, levels of resistance were generally lower (5-10 fold), although a few sites indicated higher levels and possibly the beginning of field control failures.

The Willamette Valley, where orchards are the most scattered and isolated, showed the greatest correlation between previous pyrethroid use in individual orchards and resistance levels, from highly susceptible in an unsprayed orchard to 20-fold resistance in one regularly sprayed. The Rogue River Valley, OR, and the Lake

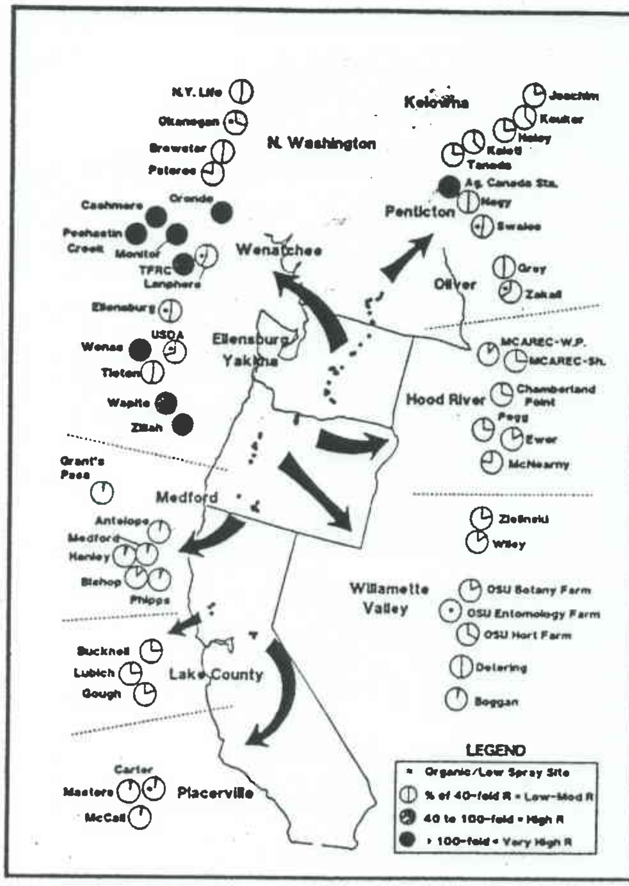

Figure 1. Geographic patterns of fenvalerate resistance in populations of pear Psylla (Psylla pyricola) from western North America (1988).

County and Placerville production areas of California showed only very low levels of resistance (10 fold).

The geographic pattern of fenvalerate resistance development is similar to that which occurred with organophosphates, showing up first in central Washington and later in Canada and the Hood River Valley, followed by the Rogue River Valley. The reasons for low resistance levels in some California growing areas where intensive pyrethroid use has occurred are not clearly understood.

The survey in 1989 (expanded to 65 sites) indicates that resistance has become higher in most orchards in Washington (over 200-fold in some), and has spread considerably in the Hood River Valley, where several field control failures have occurred. The Rogue River Valley and California orchards still show almost completely susceptible Psylla populations.

Efforts to establish baseline susceptibility levels for the newly available avermectin were complicated by limitations of the slide-dip technique: adult *Psylla* mortality continues to occur for up to 10 days, at which point high control mortality clouds the results. Dr. E. Burts has worked out an alternate bioassay involving residue testing on pear foliage, which will be more widely used next year. Also, Dr. H. Riedl has documented the correlation between *Psylla* susceptibility and state of ovariole development, which will allow better standardization of physiological age for future testing.

References:

Follett, P. A., B. A. Croft, and P. H. Westigard. 1985. Regional resistance to insecticides in *Psylla pyricola* from pear orchards in Oregon. Can. Entomol. 117: 565-573.

Croft, B. A., E. C. Burts, H. E. van de Baan, P. H. Westigard, and H. Riedl. 1988. Local and regional resistance in *Psylla pyricola* Foerster (Homoptera: Psyllidae) in western Northern America. Can. Entomol. 121: 121-129.

Burts, E. C., H. E. van de Baan, and B. A. Croft. 1989. Pyrethroid resistance in pear Psylla (Homoptera: Psyllidae) and synergism of pyrethroids with piperonyl butoxide. Can. Entomol. 121:219-223.

van de Baan[1], H. P., H. Westigard, E. C. Burts, and B. A. Croft[2]. 1989. Seasonal susceptibility to insecticides in insecticide-resistant pear Psylla, *Psylla pyricola* (Homoptera: Psyllidae). Crop Protection 8: 122-126.

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North American Diamondback Moth (DBM) Resistance Project

Because of control failures in several areas of the U.S. over the past several years, a program to assess regional differences was initiated in the spring of 1988. This project is being coordinated by T. Shelton (NY) and J. Wyman (WI). The project entailed cooperators collecting field populations from 40 different locations throughout North America. Locations ranged from Canada to Central America and from Hawaii to New Hampshire. The main thrust of the project involved testing for larval susceptibility to Ambush™, Lannate and Monitor™ using a leaf dip assay. Some of these populations were also sent to other labs where studies were conducted on pheromone trapping for insecticide resistance (Trumble and Schuster, California), behavioral resistance (Hoy, Adams and Hall, Ohio) and esterase tests (Georghiou, California). Additionally, as a spin-off to the overall project, larval populations are being tested for their susceptibility to B.t. and avermectin compounds.

Results of the testing indicate a wide range of susceptibility to the three insecticides. Using a population collected from Geneva, NY in 1987 as the standard, resistance rations (RR) were calculated for the populations collected from the 40 locations.

For Ambush the highest RR's were Belize, Central America (83.2), Albion, NY (80.4), Tifton, GA (78.4), Ransomville, NY (66.7), Lake Co., IN (62.7), South Donna, TX (56.5), and Greenville, NC (50.1), RR's from 10-25 fold were also recorded for collections from Delaware, New Hampshire, and Wisconsin.

For Lannate very high RR (4855) was recorded for Belize, RR's between 100-780 were recorded for Albion, NY, Tifton, GA, and Greenville, NC, while RR's between 50 and 100 were recorded for Long Island and Ransomville, NY and South Donna, TX. RR's between 10-50 were recorded for sites in New Hampshire, New Jersey, Ohio, Indiana, Michigan, Wisconsin, Hawaii, Texas, Florida and Ontario, Canada.

RR's for Monitor did not have such a wide range as for the other two insecticides. The highest RR recorded for Monitor was 49.4 for Belize. RR's above 10 also occurred in New Jersey, New York, Hawaii, Texas, Florida, Georgia and North Carolina.

The results of this study indicate several findings. First, reported failures to control DBM in the field may be the result of insecticide resistance, rather than environmental factors (e.g. hot, dry weather) or management practices (e.g. poor spray coverage). Second, there is a wide range of susceptibility to each insecticide throughout North America, and this variability exists not only between states but within states. Third, in most instances, if there is resistance to one insecticide there is also resistance to the other two insecticides. Fourth, it is curious that some of the highest RR's found were from upstate New York, an area one would not normally suspect as being suitable for tremendous selection pressure because of its relatively short growing season (a project is currently underway to determine if DBM are coming in on transplants from the south).

Some future directions of this project are the use of a rapid bioassay for resistance (Edelson, TX) and the development of resistance management strategies. The coordinators of the project greatly appreciate the help of all the people who sent samples for testing, the technical help of K. Apfelbeck and N. Cushing, and the advice of T. Dennehy, B. Tabashnik and R. Roush.

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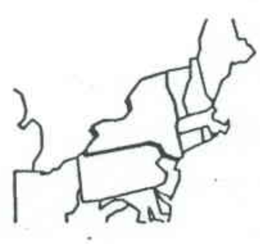

Insecticide Resistance in Field- Collected Strains of German Cockroaches

Dr. Donald Cochran, Virginia Polytechnic Institute and State University has recently reported on insecticide resistance monitored in field-collected strains of the German cockroach (*Blattela germanica*). Dr. Cochran collected forty-five strains of cockroaches from around the U.S., established the colonies in his laboratory and assayed them for susceptibility to twelve different insecticides. The assay method he utilized was the time-mortality response method in comparison with a known susceptible strain.

Only low to moderate resistance to the organophosphates chlorpyrifos, diazinon and acephate was detected although resistance to malathion was widespread. High resistance to the carbamates propoxur and bendiocarb was noted. Thirty-four of the forty-five strains had ten fold resistance to bendiocarb and high resistance to pyrethrins was observed in about half of the strains he tested.

The photostable pyrethroids have recently been introduced into the urban pest control industry for German cockroach control. The early development of pyrethroid resistance in German cockroaches is of interest due to the unusual propensity for this class of insecticide to develop resistance. Dr. Cochran found that resistance to the pyrethroids allethrin, permethrin, phenothrin, fenvalerate and cyfluthrin was detected in some of the strains examined. He stated that resistance to pyrethroids already is apparent and is likely to become an extremely serious problem in the near future if these materials are used intensively and extensively in cockroach control.

Although resistance was found in many of the strains which were tested it is important to note that all of the strains were susceptible to at least one of the insecticides used.

Examples of typical resistance ratio (RR) profiles from four of the forty-five strains of German cockroaches.

Insecticide	Strain			
	Chris	Kenly	Raddick	Knox
Diazinon	2.1	2.2	2.1	2.0
Chlorpyrifos	2.4	1.8	1.8	1.2
Acephate	1.2	1.1	0.9	1.0
Malathion	>60	>60	6.2	23.2
Propoxur	2.2	6.1	3.7	2.0
Bendiocarb	>140	>70	>60	>40
Pyrethrins	1.4	>240	>100	>140
Allethrin	1.6	1.5	>190	>180
Permethrin	1.1	1.0	1.9	>120
Phenothrin	1.0	1.3	2.5	>140
Fenvalerate	1.0	0.9	2.8	7.1
Cyfluthrin	1.0	1.1	2.0	5.4

Reference:

Cochran, D. G. 1989. Monitoring for insecticide resistance in field - collected strains of the German cockroach (Dictyoptera: Blattellidae). J. of Econ. Ent. 82:336-341.

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Insecticide Resistance in Pear Psylla and Susceptibility in a Mirid Predator in the Northwestern U.S.A.

Pear psylla, *Psylla pyricola* Foerster, is a major pest of pears in the Northwestern U.S.A. Pear psylla has developed resistance to a variety of broad-spectrum insecticides, whereas most natural enemies, such as the mirid predator *Deraeocoris brevis* Knight, have remained susceptible. Topical bioassays showed that pear psylla from the Rogue River Valley, Oregon, were 37-fold more tolerant to azinphosmethyl and 7-fold more tolerant to fenvalerate than *D. brevis*. Factors that may influence susceptibility and resistance in populations of *P. pyricola* and *D. brevis* were evaluated through biochemical and computer simulation analyses.

Studies on detoxification enzymes showed that esterase activity was 4.7- and 17.8-fold higher in susceptible and resistant pear psylla than in susceptible *D. brevis*. Higher esterase activity in pear psylla than in the predator probably contributes to the resistance observed in psylla. However, glutathione S-transferase and cytochrome P-450 monooxygenase activities were 1.5-

fold higher in susceptible *D. brevis* than in susceptible pear psylla, but similar to resistant pear psylla. Similarity of detoxification capacity in pear psylla and *D. brevis* does not explain the rapid development of resistance in pear psylla and the lack thereof in *D. brevis*.

Computer simulation studies showed that high fecundity and low immigration of susceptible individuals into populations selected by insecticides contributed greatly to rapid resistance development in pear psylla. Conversely, lower fecundity and high immigration of susceptible individuals contributed greatly to the lack of resistance development in *D. brevis*. Thus, it appears that life history and ecological factors better explain resistance in pear psylla and the lack thereof in *D. brevis* than do detoxification attributes.

Because of the lack of resistance development to broad-spectrum insecticides in *D. brevis* and other natural enemies of pear psylla, more selective chemicals are needed to allow for long term psylla control in which biological control can play a more important role.

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Monitoring for Insecticide Resistance in the Brown Planthopper, *Nilaparvata lugens*, in Indonesia

The brown planthopper (BPH), *Nilaparvata lugens* (Stal), is a major pest of rice in Indonesia, and elsewhere in Asia. Past control strategies have shown that BPH is highly adaptive to insecticides and host-plant resistance. Since BPH became a pest of major importance in Indonesia in the early 70's, insecticide resistance has been observed to organophosphates, carbamates and pyrethroids. Resistance in rice varieties containing the Bph1 gene broke down within a year after introduction in 1977. The breakdown of resistant varieties containing the bph2 gene by BPH has been observed in Indonesia since the mid 80's. The severe problems controlling BPH requires the implementation of a sustainable IPM system including insecticide resistance management. A dramatic change towards insecticide management and induced resurgence of BPH was made by the Indonesian Government in 1986 by banning 57 pesticides, previously used for rice pest control. To counter this loss, Indonesia has moved to implement sound IPM practices and training of extension personnel and farmers in pest monitoring and spray decision making.

Because of the ability of BPH to quickly develop insecticide resistance and the availability of only a few insecticides for rice pest management, insecticide resistance management is becoming an important component of the overall rice IPM program. Resistance in BPH in Indonesia has been mainly observed through field failure of compounds. The ability to detect resistance at an early stage of development is the key to successful resistance management. Therefore, the development of resistance monitoring techniques and the implementation of a resistance management program are our primary objectives.

Strains of BPH have been and continue to be selected in the laboratory with the carbamates MIPC, BPMC and the organophosphate, phenthoate. Together with a susceptible strain, these strains are being used as reference strains for the comparison of resistance levels with field populations. Toxicity of compounds is evaluated using a dip test, in which BPH are placed in fine-meshed wire screen cages and dipped in serial dilutions of formulated insecticides.

Field detection of resistant populations of BPH are being carried out using a microplate assay system. Esterases are the primary mechanism of resistance in BPH (Chang and Whalon 1987; van de Baan, Whalon and Untung unpublished data). The microplate assay is based on the detection of esterase activity in individual insects. This biochemical assay is proving very useful because it provides information about resistance frequencies within populations. Also smaller numbers of insects are needed in the assay, and it is more sensitive and less time consuming than toxicity tests.

A field resistance monitoring kit is also being evaluated using a portable photometer, which allows for the detection of resistance levels in populations of BPH in the field. If successful, this approach will be a very useful tool for large scale resistance monitoring of BPH in Indonesia.

References:

Chang, C.K. and M.E. Whalon. 1987. Substrate specificities and multiple forms of esterases in the brown planthopper, *Nilaparvata lugens* (Stal). Pestic. Biochem. Physiol. 27: 30-35.

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14-C Pyrethroid Hydrolysis by Multiple Forms of Esterases and Their Relations to Pesticide Resistance in Colorado Potato Beetle

Substrate specificities and pyrethroid hydrolyzing activity in the cell free systems of two resistant, Long Island (Rl) and Macomb (Rm), and a succeptible Arizona (S) strain of Colorado potato beetle (CPB) have been examined *in vitro*. Rm had high esterase activity followed by Rl. Hydrolysis of ^{14}C-permethrin by R CPB was 3-fold greater for trans and 2-fold greater for cis isomer when compared to S strain. Significant levels of 14-C-carbaryl and 14-C-malathion hydrolysis were found only in Rm strain over the Rl CPB.

Gradient PAGE analysis of CPB body homogenates resolved into 13 esterase (E) bands in S, 20 in Rl and 21 in Rm CPB. Based on mobility patterns these E bands were divided into four different groups (I to IV) comprising 4 each of S, Rl & Rm in group I; 4 (S,Rl) & 5(Rm) in group II; 3(S), 4(Rl) & 5(Rm) in group III, and 2(S), 8(Rl) & 7(Rm) in group IV. Although different quantitatively, the E-bands hydrolysing alpha-NA were also active in hydrolysing beta-NA with few exceptions.

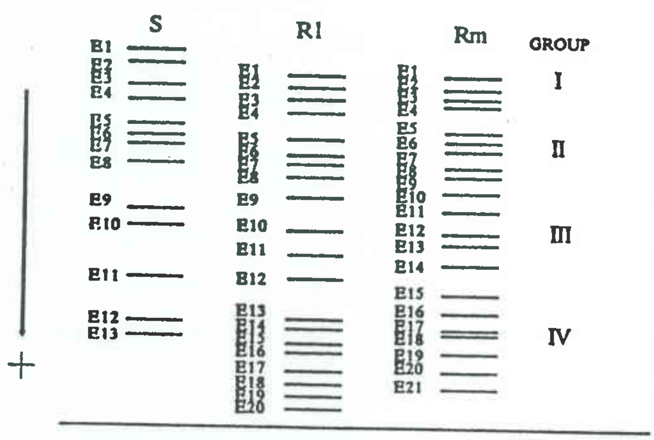

Figure 1. Electrophorotograms of Susceptible Arizona (S) Resistant Long Island (Rl) and Macomb (Rm) Strains of Colorado Potato Beetle.

Based on degree of sensitivity to 0.1mM eserine sulfate (Ese), p-hydroxy mercury benzoate (PHMB) and S,S,S-tributylphosphorotrithioate (DEM), the esterase bands were classified into cholinesterases (CH), arylesterases (Ar), carboxyesterases (CE) and esterases resistant to all inhibitors (ER). Only E-11 in S and E-4 in Rm were sensitive to Ese alone, E-3 in S, E-5, 16, 19 in Rl and E-7 to 9, 18, 21 in Rm were Ar and the rest of them were either CEs or ERs. The composition and pattern of the esterases in group IV were most similar between Rl and Rm CPB.

Hydrolysis of 14C-trans permethrin was observed in only three E-bands (E2, 11, 13) in S; nine E-bands (E8-10, 12, 15, 17-20) in Rl and by twelve E-bands (E1, 4, 7, 9, 13-18, 20, 21) in the Rm strain. Interestingly, most of the pyrethroid hydrolysing esterases were located in group IV in both Rl and Rm CPB. The S CPB had much fewer bands (0-2) in the IV region when compared to Rl and Rm.

These results strongly support the contention that the mechanism of pyrethroid resistance in Rm and to some extent in Rl CPB can be attributed to number and quality differences in pesticide hydrolysing abilities of group IV esterases. Additionally, through PAGE analysis, the presence or absence of this esterase pattern (particulerly group IV) may be utilized as a tool in diagnosing resistant CPB.

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Insecticide Resistance in the Colorado Potato Beetle, *Leptinotarsa decemlineata*, in Michigan.

Resistance to insecticides in the Colorado potato beetle, *Leptinotarsa decemlineata* (Say), has been severe for a number of years in the northeastern U.S. Resistance is reported from North Dakota and Minnesota (Radcliffe and Watrin 1986) and problems are becoming very common in Michigan. Numerous populations in Michigan show broad resistance to organophosphate, carbamate, chlorinated hydrocarbon, and pyrethroid insecticides and control failures are frequent.

Populations of CPB were collected from commercial fields or volunteer potatoes or weed hosts. Strains showing resistance to azinphosmethyl, permethrin, or carbofuran were inbred and laboratory-selected at ca. 80% mortality for 5 or more generations. An additional strain was created by large-scale field selection of larvae with carbofuran (Table 1).

Table 1. Selection for carbofuran resistance from susceptible field populations.

Generation	LD50 (ug/beetle) Carbofuran	Azinphosmethyl
Before selection	0.6	1.4
Selection (in field F1 (99.9% mortality of larvae)	34.8*	-
Selection (in lab) F2 (ca. 80% mortality of adults)	93.9	9.2
Selection (in lab) F3	100	18.1

*Heterogeneous population

Resistance Mechanisms:

Resistance mechanisms were identified through synergism and cross-resistance studies and analyses of enzymatic activity (Ahammad-Sahib et al 1989). Mixed-function oxidase (MFO) enzymes are involved in resistance to permethrin and azinphosmethyl, although different MFO's appear to be involved, since no cross-resistance occurs. Esterase activity was also identified. Knock-down resistance to permethrin was characterized by cross-resistance to DDT, delayed effect of permethrin on treated beetles, recovery of "knocked-down" beetles in 2 to 4 days, and no effect of synergists (Ioannidis and Grafius 1988). Penetration of radio-labeled permethrin into resistant CPB adults was reduced. Carbofuran resistance was characterized by no synergistic activity, no cross-resistance to permethrin, and low level cross-resistance to azinphosmethyl. There were no low or intermediate levels of carbofuran resistance. Individuals were either highly sensitive or virtually immune to any dose. Preliminary in vitro assays indicate altered cholinesterase activity in carbofuran-resistant beetles, compared with susceptible strains (Weirenga and Hollingworth, unpubl.). Beetles from the Long Island New York culture are also resistant to carbofuran but show synergistic activity and a high level of cross-resistance to azinphosmethyl, suggesting a different mechanism. Beetles collected from Michigan potato fields often show resistance to several groups of insecticides and multiple resistance mechanisms. High levels of heterogeneity (high variability, high X2 values, long log-profit slopes) are also common in field populations, as expected.

Inheritance Studies:

Crossing and back-crossing between resistance in-bred strains and susceptible beetles indicates that azinphosmethyl resistance involves one main gene (autosomal, incompletely dominant) and probably one secondary gene. Carbofuran resistance is inherited as a single autosomal incompletely dominant gene (or very closely linked genes). Repeated back-crossing of carbofuran resistant with susceptible beetles continues to give 1:1 segregation.

The extremely rapid appearance of carbofuran resistance observed in our selection experiment and in commercial situations is explained by: 1) very high toxicity of carbofuran to susceptible beetles and the resultant high selection pressure, 2) the high level of resistance (virtual immunity) contributed by this single near-completely dominant gene, and 3) a lack of other mortality factors (chemical or non-chemical) in many situations.

Resistance Monitoring:

Wide-scale resistance monitoring was conducted in 1988 and is continuing in 1989. A resistance test kit has been developed consisting of a series of petri dishes with filter papers treated with discriminating concentrations of representative organophosphate, pyrethroid, carbamate, or chlorinated hydrocarbon insecticide (commercial formulations of phosmet, esfenvalerate, carbofuran, and endosulfan, respectively) or an esfenvalerate + PBO treatment.

Concentrations are based on tests of resistant and susceptible cultures and field populations. For carbofuran, a wide range of concentrations can be used since susceptible beetles are highly sensitive and resistant beetles are practically immune. For esfenvalerate, phosmet, and endosulfan, the concentration providing the most discrimination between resistant and susceptible populations (based on G-statistic) was used (usually 80 - 90% mortality of susceptible beetles). PBO was added in proportion to normal field use rates. Shelf-life tests were conducted to insure that effective concentrations were stable for at least 2 weeks at room temperature. Azinophosmethyl was not stable and could not be included in this type of test. Results were verified on representative field populations using standard topical applications and LD50 analyses. Field-level validations are proceeding, to compare the results of test kits with results of small plot insecticide trials.

Conclusions:

Insecticide resistance in Michigan is extremely diverse in severity of resistance, materials involved, and mechanisms. All stages of susceptibility/resistance are present and populations exist that express single and multiple resistance mechanisms. Differences between Michigan populations and results from other locations, such as effective synergism of organophosphates with PBO and altered cholinesterase activity as the primary carbofuran resistance mechanisms, may be due to the level of resistance in Michigan populations as well as the historical progressions of insecticide use and selection for resistance.

References:

Ahammad-Sahib, K.I., M. E. Whalon, R. M. Hollingworth, P. M. Ioannidis, and E. J. Grafius. 1989. The role of mixed-function oxidase and other metabolic enzymes in insecticide resistance in Colorado potato beetle. Pest. Biochem. Physiol. (submitted).

Ioannidis, P. M. and E. Grafius. 1988. Mechanisms involved in permethrin resistance of the Colorado potato beetle, Leptinotarsa decemlineata (Say) (Chrysomelidae) with particular reference to knockdown resistance. Intern. Congr. Entomol., Vancouver, Canada (Abstract).

Radcliffe, E. B. and C. G. Watrin. 1986. Pyrethroid resistance in Red River Valley potato beetles. Valley Potato Grower. Feb. p. 8-12.

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Regional Coordinator's Reports

The Loss of Susceptibility to Dimethoate, Methidathion and Bifenthrin in Banks Grass Mite Following Pesticide Exposure in the Field

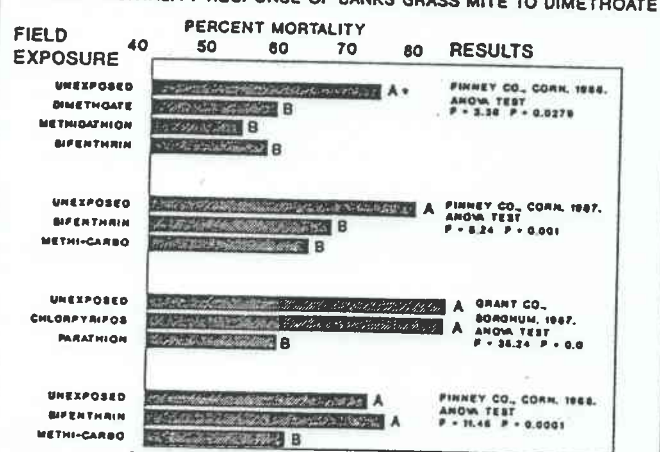
Levels of resistance to dimethoate, methidathion and bifenthrin in Banks grass mite, *Oligonychus pratensis* (Banks) were estimated following single exposures to pesticides in the field. Vial residue bioassay technique with a dosage range of 0.001 to 1000.0 /vial [in log scale] were used. Ten, adult, female mites were added to each vial. Mortality was recorded 24 hours later. Mites were scored as dead if they failed to make any movement when probed with a fine brush. Bioassays were replicated three times.

The study was initiated in 1986 and continued through 1988. Banks grass mites tested in the bioassays were collected from plots in acaricide evaluation trials conducted in southwest Kansas. In 1986, mites were collected from the following treatments in a small plot acaricide trial in corn: dimethoate, methidathion, bifenthrin and the untreated check. In 1987 and 1988, mites were collected from the following treatments in aerial tests in corn: bifenthrin, carbofuran + methidathion and the untreated check. In 1987, mites also were collected from the following treatments in an aerial test of greenbug insecticides in sorghum: parathion, chlorpyrifos and the untreated check.

Percent mortalities were corrected using Abbott's formula and then transformed to arcsine. ANOVA was applied to the data to test the effects of field exposure to pesticides on the mortalities across the concentrations and replications. The means were separated using Duncan's multiple range test.

Mites taken from the pesticide-treated plots (except chlorpyrifos) had significantly lower mortalities to dimethoate compared to the mites from the corresponding untreated check plots (Fig. 1). Mortalities to methidathion was significantly lower in pesticide-exposed mites only in 1988 test (Fig. 2). Field-exposure to methidathion or methidathion combinations caused significant loss of susceptibility to dimethoate (Fig. 1) and bifenthrin (Fig. 3); but the susceptibility to methidathion was reduced to a lesser degree (Fig. 2). Pesticide-exposed mites had significantly lower mortalities to bifenthrin than did the mites from the untreated check plots in several tests (Fig. 3).

FIG.1 MORTALITY RESPONSE OF BANKS GRASS MITE TO DIMETHOATE



*Bars followed by the same letter in a test are not significantly (P = 0.05) different.

FIG.2. MORTALITY RESPONSE OF BANKS MITE TO METHIDATHION

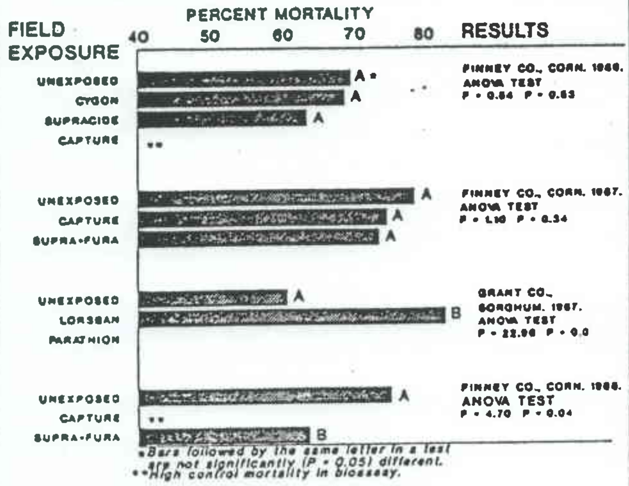
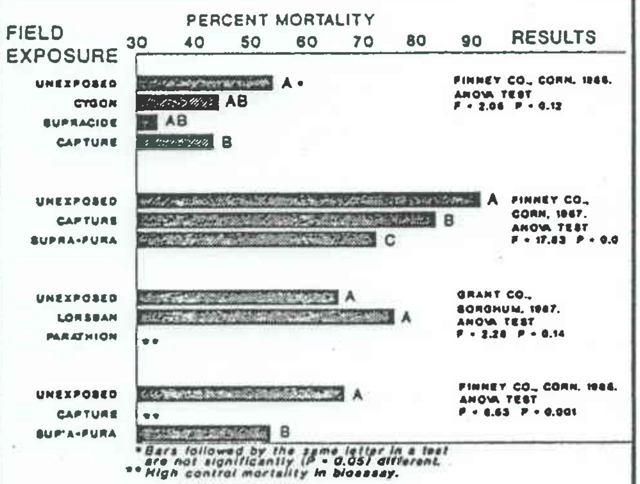


FIG.3. MORTALITY RESPONSE OF BANKS GRASS MITE TO BIFENTHRIN



The results of this study indicate increased incidence of resistant Banks mites following field exposures to single pesticide treatments. The levels of resistance to dimethoate, methidathion and bifenthrin in Banks grass mites varied considerably depending on the type of the pesticide they had been exposed to in the field. This suggests that when multiple applications of acaricides are necessary, the sequence in which the acaricides are applied should be taken into consideration. For example, the application of dimethoate may be effective early in the season before other pesticides have been used, but it may not be effective later in the season after methidathion or bifenthrin have been used.

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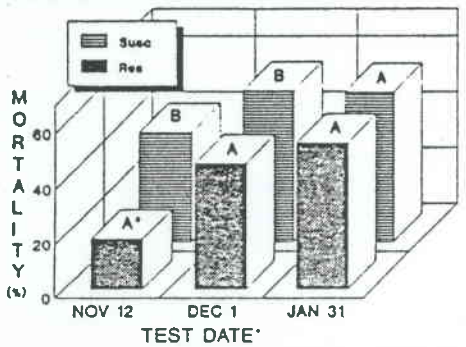
Insecticide Resistance in Greenbugs in Western Kansas

Differences of resistance to parathion and chlorpyrifos-methyl in two strains of greenbug, *Schizaphis graminum* (Rondani), were studied. During August of 1988, a greenhouse colony was established with greenbugs collected from a parathion-failure sorghum field in M‹ ‹de Co., Kans. This colony was compared with a 3-year old greenhouse colony (designated as susceptible), using a vial residue bioassay technique.

Vials used in the study were treated using a serial dilution of technical material in acetone to provide test doses from 0.001 to 1000.0 /vial (spaced in a logarithmic scale). Five medium to large greenbugs were added to each vial and each bioassay was replicated six times. Bioassays were conducted three times (Nov., Dec., 1988, and Jan., 1989). In the first bioassay (Nov. 12), response (number dead) was recorded after 8 hours. In the 2nd and 3rd tests, the response (aphid dead or incapable of coordinated movement) was recorded after 12 hours. Bioassay responses (%) were corrected using Abbott's formula and transformed to arcsine. The ANOVA was applied to test the effect of strains on the responses in aphids across all concentrations. Means were separated using Duncan's new multiple range test. Greenbugs from both colonies were also tested for esterase levels using gel electrophoresis in March, 1989 in cooperation with William C. Black IV and L. John Krchma in Manhattan, Kans.

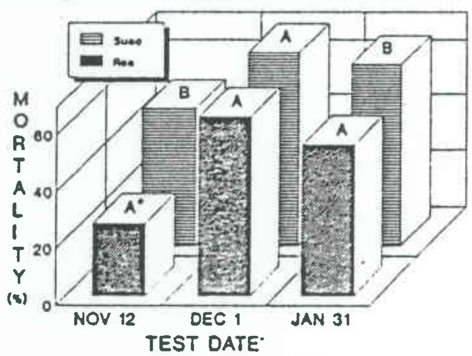
In all tests, the proportion of greenbugs responding to test insecticides in the bioassays was lower in greenbugs from the parathion-failure field than from the susceptible colony. Differences were statistically significant in the 1st and 2nd bioassays with parathion (Fig. 1) and the 1st and 3rd bioassays with chlorpyrifos-methyl (Fig. 2). These decreased levels of responses were exhibited several months after their last exposure to pesticides in the field. Results suggest the presence of insecticide resistance in greenbug populations located in one area of western Kansas. They also indicate the potential of cross resistance, since the greenbugs from the parathion-failure field appear to be resistant both to parathion and chlorpyrifos-methyl. The results of the bioassays were further supported by the gel electrophoresis study that detected significantly higher levels of esterase in the greenbugs from the parathion-failure field. Increased levels of esterase are often associated with pesticide resistance in arthropod populations.

Fig.1. Response of resistant and susceptible greenbugs to parathion. [Avaraged across all concentrations].



* Bars on same test date with same letters are not statistically different (P•0.05)

Fig.2. Response of resistant and susceptible greenbugs to chlorpyrifos-methyl. [Av. across all concentrations].



* Bars on same test date with same letters are not statistically different (P•0.05)

A more extensive survey needs to be done to determine the extent of the insecticide resistance problem in greenbugs in western Kansas and to examine the chemicals that may be showing cross resistance.

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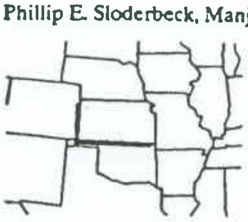

Report for Central Midwest Region, Illinois, Iowa and Missouri

Western Flower Thrip Resistance in Greenhouses - Kansas City, Mo.

Greenhouse operators have had widespread control failures with organophosphates, carbamates, and pyrethroids against the western flower thrips, *Franklinella occidentalis*. Control failures documented in the Kansas City metro area have been routine and dramatic, with the regular loss of entire crops of ornamentals. Resistant thrips have recently moved from greenhouse to the outside and are currently infesting ornamental crops adjacent to the greenhouses. A tank mixture of Talstar (bifenthrin) and Avid (abamectin) is currently the only insecticide treatment still effective. These thrips have developed resistance despite the fact that operators were rotating insecticides. Laboratory bioassays are in progress to determine the extent and magnitude of resistance. There has been no formal documentation, monitoring or research on resistance on these pests in Missouri.

Hornfly Resistance to Pyrethroid Ear Tags

Resistance has been documented in several states of the Midwest and southeastern United States (Sparks, el al 1985 and Weinzierl et al 1987). Resistance, according to Dr. rick Weinzierl, of the University of Illinois extension, can be attributed to the residual of the ear tags. The mechanism is suspected to be kdr. Presently, there is a shift away from pyrethroid tags to those comprised of an organophosphate or an O-P-pyrethroid mix. The O-P tags are effective in controlling hornfly and cross-resistance of resistance has not as yet been documented to them. To O-P-pyrethroid tags, however, are not very effective. Other control measures recommended include feed additives and dust bags and oilers containing Co-Ral (coumaphos).

Hairy Fungus Beetle Resistance to Pirimiphos-Methyl and Malathion

In Illinois, hairy fungus beetle resistance to malathion and pirimiphos-methyl has been documented (Weinzierl, 1989). Resistance levels among populations from treated bins in comparison to those of untreated bins are 38x to pirimiphos-methyl and 66x to malathion.

References:

Sparks, T. C., S. S. Quisenberry, J. A. Lockwood, R. L. Byford, and R. T. Roush. 1985. Insecticide resistance in the horn fly, Haemotobia irritans, J. Agric. Entomol. 2:217-233.

Weinzierl, R. G. Cmarik, G. Zinn, and D. Faulkner. 1987. Pyrethroid ear tags for pastured cattle: horn fly resistance in Illinois. In: Proc. Illinois Agriculture Pesticides Conference 1987. Coop. Ext. Serv., Univ. of Ill., Urbana-Champaign. pp. 122-143,

Weinzierl, R. G. and R. P. Porter. 1989. Hairy fungus beetle (Coleoptera: Mycetophagidae) resistance to pirimiphos-methyl and malathion. (In press).

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Resistance Monitoring

Detection and Analysis of Insecticide Resistance in Lygus Bugs

Lygus bugs, especially *Lygus hesperus* Knight, are serious pests of alfalfa seed production. Resistance to the trichlorfon has been a long standing problem. The insect infests other crops as well and, at times, can be one of the worst pests of western cotton. Characterizing *L. hesperus* resistance mechanisms could benefit many aspects of western crop protection.

The resistance was found to be related to levels of carboxylesterases which may be detected by electrophoresis or simply by crushing adult insects on 1-naphthyl propionate-treated filter paper. The paper is spotted with Fast Blue B dye. If more than 10% of the insects show a definitive change in spot color, the registered rates of trichlorfon application will not provide satisfactory control of an infestation. This conclusion is based upon correlating spot test results to LC50 and LC50 to field plot efficacy.

Resistance may also be detected by contact biological assays of insects collected in the field. Treated glass vials have been used for much of the bioassay work, but a much more convenient and cheaper method is to use small "zip-lock" bags made of acetone-resistant plastic. Each bag is treated with 5 l acetone containing technical grade trichlorfon and the bag is flattened to spread the solution. The acetone is quickly dried with a forced air stream. In the field, a small cork is placed in the bag along with a bit of unsprayed alfalfa. Five bugs are placed in each bag (appropriate replicates of concentrations and controls) and these are incubated in an inexpensive incubator for 8 hours. In treating the bags, it is important not to take too long and not to use too much solvent.

Synergism has been tested by holding *L. hesperus* in DEF-treated vials for ca. 1 hour and then transferring them to bioassay bags. Extremely high resistance levels have been discovered in which DEF fails to restore total susceptibility in bioassay trials. Trichlorfon LC50 values, ca. 4 g/bag for lower susceptibility levels, were reduced from more than 170 ug/bag to 6-8 g/bag by DEF. We consider this incomplete synergism based upon experience in matching bioassay data to field results.

Synergist ratios averaged 1.8 in 4 Utah fields (area of virtually no insecticide use) and 42.1 in five Oregon and Idaho fields where insecticide use is intensive and regular. This may imply total dependence upon carboxylesterases but synergist difference calculations, which we feel make much better use of bioassay data, showed a definite difference between relative percent synergism values for the susceptible and resistant populations. This is a result encountered when two resistance mechanisms contribute to one another's effect (Environ. Entomol. 13:348, 1984). Extreme *L. hesperus* resistance is based upon such contributions.

The extreme resistance is associated with increased carboxylesterase activity (4 to 6 fold) plus an acetylcholinesterase which is insensitive to inhibition by paraoxon. Carboxylesterase Km values for resistant *L. hesperus* were not significantly different from those which were susceptible but Vmax was ca. 5 times greater for resistant insects. There was no difference in paraoxon pI50 values for the carboxylesterases of susceptible and resistant insects.

A small amount of acetylcholinesterase could be inhibited by paraoxon in highly resistant *Lygus hesperus*, but most could not be readily inhibited. Km and Vmax values for acetylthiocholine did not differ between susceptible and resistant insects. This may be an advantage for the resistant insects; acetylcholinesterase can perform its normal catalytic role regardless of its insensitivity to organophosphates.

The combination of target site resistance with carboxylesterases may explain why some populations of *L. hesperus* do not fit the expected relationship between bioassay and esterase spot test results. Preceding the spot test with DEF exposure may efficiently and quickly identify insects with combined resistance mechanisms. Increasing proportions of *L. hesperus* adults giving positive spot tests after being treated with DEF occur with LC50 values of 10 g/bag or higher. LC50 values of 100 g/bag have nearly 90% of the insects in which positive spot tests for esterases appear despite DEF pre-exposure of the adults.

Finding mechanistic evidence for *L. hesperus* resistance to trichlorfon is consistent with long-standing grower complaints in Idaho and Oregon where alfalfa seed culture depends partly on protecting the crop while leafcutting bees are pollinating the field. Loss of short-lived, effective, insecticides is a tremendous problem for no methods have been developed to control *L. hesperus* infestations during pollination. Alfalfa seed production is minor in the sense of acreage but most of the US production is from the northwest and it is required for extensive replantings of alfalfa hay fields throughout the nation.

Beyond this economic significance, approaching a problem of insecticide resistant insects with analyses of field populations using disposable, contact biological assays and spot tests for esterases (if synergism shows them to be involved) can provide a practical connection between the interests of the grower and of science. Effects of multiple, contributing resistance mechanisms should be considered. In our case, evaluating synergism by differences and combining synergism and spot test methods provided useful hypotheses for guiding research or interpretation of results.

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Modeling

Modeling: Mixtures vs Rotations

A major topic of discussion centers on whether to use mixtures or rotations in insecticide resistance management. With mixtures, individual insects that receive a dose of one insecticide receive a simultaneous dose with another insecticide. A rotation is defined as a planned sequence of use, first of one chemical, and then another. I was puzzled by this debate, because, on the one hand two experts, Curtis (1985, 1987) and Mani (1985) have used simulations to reach the conclusions that mixtures are better than rotations. On the other hand, the equally expert Holloway and McCaffery (1988) and Roush (1989) have produced simulations which show that rotations can be better than mixtures. Roush concludes: "in most cases, I suspect that differences in persistence or ineffectiveness of control will be sufficient that a mixture approach can be discarded".

As I have previously studied the evolution of multi-locus systems, it was not difficult to produce simulations of the evolution of resistance with two insecticides. The model assumes that a separate gene codes for resistance to each insecticide. My model agrees in broad outline with those of the above authors, and permits variations of: fraction of the population treated, percent mortality of the treated individuals, relative persistence of the insecticides, dominance of the resistance loci, linkage, and initial gene frequencies. The model is essentially a standard constant fitness model with variable dominance. The fitnesses were combined multiplicatively.

This model can reproduce any of the results of the above authors, at least approximately. There are slight differences in the exact numbers of generations to resistance, but this could be due to small errors in my or their models, or, perhaps more likely, to differences in assumptions and rounding errors.

Both sides of the argument are right. Mixtures will last longer (often thousands of times longer) than rotations under many conditions. But if one of the compounds is less efficacious or persistent than the other, or the resistance alleles are effectively dominant (Holloway and McCaffery, 1988; Roush, 1989), there can be a small advantage to using a rotation. These results are also sensitive to the proportion of the populations that is treated: with a lower proportion treated: (roughly equivalent to higher immigration), mixtures become more beneficial.

Curtis and Mani appear only to have used parameter values which would give superiority of mixtures, whereas Holloway, McCaffery, and Roush perhaps intentionally overemphasize the generality of their results showing that rotations are better. My feeling is that the enormous gains that can be made by using mixtures are worth achieving if possible: each case should be carefully researched. Mixtures will typically cost more than twice as much per season as rotations, but in cases where long-term insect control is valued highly, for example in a Malaria eradication program or in a cotton industry of national importance, a mixture may be worth the additional annual cost.

I am grateful to the cited authors for sharing with me their thoughts and unpublished results. I am intending to use the above model for teaching purposes: if anyone is interested in a copy, which runs on an IBM PC with an 8087 "math coprocessor", I can probably supply it for the price of a disk and postage, about $5.00.

References:

Curtis, C. F. 1985. Bull. Ent. Res. 75:259-265.

Curtis, C. F. 1987. In Combating Resistance to Xenobiotics (Ford, M. G., Holloman, D. W. Khambay, B. P. S. and Sawicki, R. M., eds.), pp. 150-161, Ellis Horwood.

Holloway, G. J. and McCaffery, A. R. 1988. Brighton Crop Prot. Conf. 1988: 465-470.

Mani, G. S. 1985. Genetics 109:761-783.

Roush, R. T. 1989. Pestic. Sci. (in press).

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