## Abstract

Henneberry, T.J., and R.M Faust, eds. 1999. Silverleaf Whitefly: National Research, Action, and Technology Transfer Plan, 1997–2001 (Formerly Sweetpotato Whitefly, Strain B): Second Annual Review of the Second 5-Year Plan, Held in Albuquerque, New Mexico, January 31–February 2, 1999. U.S. Department of Agriculture, 1999–01, 195 pp.



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## Editors' Comments

Henneberry, T. J. and R. M. Faust (eds.) 1999 Silverleaf Whitefly Supplement to the 5-Year National Research, Action, and Technology Transfer Plan (1997-2001). Albuquerque, NM, January 31-February 2, 1999.

This publication contains research, extension-education, industry and action agency reports of progress contributing to our knowledge of the whitefly complex and to the development of ecologically acceptable whitefly management systems. The multiagency cooperative effort has, since 1992, provided a forum for information exchange, complementary, coordinated and cooperative research programs, avoidance of duplication of effort, and optimum return for expended research dollars. The result of the joint partnerships has been solutions and technology transfer to the stakeholders in the agricultural communities. These accomplishments have been achieved within a compressed timeframe, in large part, due to openness of communications, sharing of expertise and focus on common goals. The editors sincerely thank all those who participated in the second annual review of the new research and technology transfer plan.

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**Acknowledgments:**
The USDA Silverleaf Whitefly, Research, Education and Implementation Coordinating Group; Annual Review Program Chairs; Local and State Coordinators; SLWF Program Planning and Review Committee; and the Silverleaf Whitefly Working Group sincerely appreciate the contributions of all the participants and those who have helped in organizing the 1999 meeting. Recognition is extended to the University of California Center for Exotic Pest Research for their support and cooperation in meeting site selection and program organization.

## Preface

The Silverleaf Whitefly (SLWF), *Bemisia argentifolii* Bellows and Perring, National Research, Action, and Technology Transfer Plan (1997-2002) outlines a coordinated, cooperative program involving federal and state agencies, universities, and the agricultural industry. Research needs, goals and objectives, and technology transfer to clientele (scientific community, legislators, regulators, the agricultural industry, and the public) are reviewed on an annual basis. The plan is flexible allowing responsiveness to changing needs and priorities with appropriate adjustments to terminate, redirect, or add priorities based on funding, current knowledge, and program needs. The program goals are the development of environmentally and socially acceptable areawide, community-based silverleaf whitefly management.

USDA agencies (ARS, APHIS, and CSREES), state agencies, state agricultural experimental stations, and the cotton, vegetable, ornamental, nursery crop and chemical industries participated in development of the plan to promote research, establish priorities, avoid duplication of effort, and maximize the use of existing resources.

The USDA Silverleaf Whitefly Research, Education, and Implementation Coordinating Group coordinates USDA interagency activities and partner state agricultural experiment stations activities. The Silverleaf Whitefly Working Group is composed of members of participating agencies and meets annually to maintain communication with the USDA Coordinating Group and the Silverleaf Whitefly Program Planning and Review Committee.

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## Executive Summary

The devastating impact of *Bemisia* during the 1990's on field and vegetable crop production and the ornamental's industry resulted in crop losses exceeding 200 million dollars annually, losses in farm jobs, and losses also occurred in associated farm support, marketing, storage and shipping industries. The principle states impacted in field production, although sporadic infestations occurred in other states, were California, Arizona, Texas and Florida and for the greenhouse and nursery crops states along the Atlantic seaboard, Midwest and California. This emergency situation created the need for a coordinated, cooperative, multiagency approach to develop effective control and whitefly management methodology. The first 5-year national research and action plan was active from 1992 to 1996. Following its termination, a second 5-year was initiated to cover the period from 1997 to 2001. Extensive research achievements have provided interim solutions and a better understanding of the SLW problem. Effective controls have been developed on most major crops and losses reduced. Technology transfer to growers and the scientific community has resulted in greatly improved, more efficient and environmentally acceptable whitefly management methodology. The priority research areas of the current plan are: (A) biology, ecology, and population dynamics; (B) viruses, epidemiology, and virus-vector interactions; (C) chemical control, biopesticides, resistance management, and application methods; (D) natural enemy ecology and biological control; (E) host plant resistance, physiological disorders, and host-plant interactions; and (F) integrated and areawide pest management approaches, and crop management systems.

A complete management system for silverleaf whitefly is a goal for the future, but at present, it is in the formative stages. Extensive fundamental, ecological, and biological research on the silverleaf whitefly and its natural enemies has revealed potential components for incorporation into an ecologically-based management system. Farm practices, such as water-use patterns, proximity of alternate host crops, and spatial considerations, are being implemented to achieve whitefly population reduction. Knowledge of the complex host interrelationships among cultivated crops, crop growing sequences, and urban community hosts has focused awareness that the entire farm community must concern itself with population suppression programs. The mechanisms involved in the complex interaction of host plants and silverleaf whitefly population dynamics are largely unknown.

Although insecticides alone or in combination have been found to provide adequate control on major cultivated crops, insecticide resistance management is a particularly important factor that must be addressed. Development of biological and other nonchemical control, disease and silverleaf whitefly resistant plant types, and an expansion of our current knowledge of whitefly and natural enemy taxonomy, physiology, biochemistry, and genetics are essential to development of long-term management systems.

## Introduction

The SLWF continues to be a serious economic problem in the United States. Control is heavily dependent on the use of insecticides alone or insecticide mixtures. The associated environmental and social problems as well as the occurrence of insecticide resistance have been anticipated and ameliorated somewhat by the use of action thresholds and insecticide-resistant management (IRM) programs. Adult and immature SPW sampling methods and action thresholds have been developed and validated for cotton and melons in the field and for greenhouse crops which are particularly helpful in the decision-making process for control. This approach has reduced insecticide use, cost of production, and development of insecticide resistance while maintaining crop yields. Resistance monitoring is accomplished with yellow sticky card vial and leaf dip bioassay techniques. A hydroponic bioassay system has been developed for systemic insecticides. SLWF insecticide-resistance levels differ in different geographic locations and with different insecticides. There is some level of resistance to organophosphates, pyrethroid, carbamate, and chlorinated hydrocarbon insecticides at various locations within the United States but chemical control and IRM have been highly effective on a short-term basis. New chemistry such as the insect growth regulators, provide additional options in IRM programs and may delay or reduce resistance to conventional chemistries. In Florida, the introduction of imidaclorprid, a chloronicotynyl systemic insecticide, for control on vegetables has had a major impact on reducing whitefly populations in Florida. Experience has taught the entomological community that the probability of continuing long-term insecticide based management efficacy is remote. Thus, extensive effort is being made to develop management systems that incorporate cultural, biological, and nonchemical methods into chemical control-IRM-based control methods. Results have shown that these integrated systems are most effective when implemented as community action efforts.

The types of crop grown and temporal and spatial relationships with other crops are considerations in whitefly population dynamics. The extensive numbers of weed, ornamental, nursery stock and cultivated crop-host-plants provide nutritional and reproductive host continuity and population growth biomass. At present strategies for utilizing SLWF dispersal in management is limited. However, growers have developed an awareness of the importance of crop sequencing, wind direction, SLWF dispersal, and the proximity of host crops when establishing new plantings. Equally important in this respect has been strict adherence to early harvests of all SLWF host crops and destruction and plowdown of crop residues. In areas, where applicable, growers and urban community residents have participated in destruction of weed hosts to reduce another source of migrating SLWF. Although, these efforts have not been quantified in relation to effects on SLWF populations, they represent good farm practice and growers have been encouraged to implement them.

Crop production inputs have measurable influence on SLWF population dynamics. For example, higher SPW populations occur in water-stressed cotton and water management to avoid stress implemented in cotton production. Row covers and other insect exclusion and reflective type materials for repelling SLWF have been adopted and are partially effective in some cropping systems.

Biological control and varietal plant resistance are expected to play an important role in long-term management of SLWF populations. High levels of indigenous natural enemy activity have been identified in cotton, vegetable, and peanut ecosystems, suggesting that natural enemy augmentation and conservation approaches may be important avenues for exploitation in SLWF management in the future. Foreign explorations have resulted in collection of numerous exotic parasite and predator species that are being considered as potential biocontrol agents. Release of some exotic parasitoid species have been accomplished with variable results. Monitoring is continuing to identify and verify establishment and impact on SLWF populations.

SLWF plant resistance in several crop types has been identified, as well as for tomato mottle and other diseases. Resistant germplasm has been identified in alfalfa, peanut, melon, cotton, broccoli, collard and tomato. The hirsute leaf character has been recognized to support higher whitefly populations than smooth-leaf types and verified by many scientists. Host plant preferences for melons, cotton, broccoli and lettuce appear related to the amount of vascular tissue per unit of leaf area and the proximity of vascular bundles to leaf surfaces. Also, leaf surface morphology has been shown to play an important role in SLWF nymph establishment. Studies on plant-insect interactions, physiological disorders and mechanisms of resistance and modes of action for whitefly and disease resistance provide leads for scientists for identifying resistant germplasm for incorporation into agronomic types.

Extension and education activities have played essential roles in implementation of SLWF management. Integration of risk assessment information, spatial analysis, geographic information systems, communications networking, ecological modeling, and extension programs are continually improving our efforts to provide current and timely information to producers for implementation.

The goal of integrating chemical control resistance management, crop sequencing and host-free periods, crop residue and weed destruction, SLWF population and plant disease monitoring, and other cultural controls and management options is considered a high priority for implementation. Research of the current 5-year plan focuses heavily on these issues and technology transfer.

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[1] The “5-Year National Research and Action Plan for Development of Management and Control Methodology for the Silverleaf Whitefly (formerly, sweetpotato whitefly, Strain B)” was initiated in 1992 and terminated in December 1996.

**Table 1. Numbers of Research Abstracts for the 1998-1999 Silverleaf Whitefly Annual Progress Review of the USDA Silverleaf Whitefly National Research, Action and Technology Transfer Plan (1997–2001).**

| | Research Priorities[a] | | | | | | |
|---|---|---|---|---|---|---|---|
| Agency[b]/State | A | B | C | D | E | F | Total |
| | | | 1998 Review, Charleston, SC | | | | |
| APHIS | | | | 11 | | | 13 |
| ARS | 12 | | 6 | 13 | 6 | 1 | 38 |
| AZ | | | 1 | | | 2 | 3 |
| CA | 1 | 1 | 7 | 5 | 6 | 3 | 23 |
| FL | 1 | 1 | | | 1 | | 3 |
| GA | | | | | 1 | | 1 |
| NY | | | | | | | |
| OH | | | | | | | |
| TX | | | | 2 | | | 2 |
| OTHERS | 3 | | | 1 | 1 | 1 | 6 |
| TOTAL | 17 | 2 | 14 | 32 | 15 | 9 | 89 |
| | | | 1999 Review, Albuquerque, NM | | | | |
| APHIS | | | | 3 | | 6 | 9 |
| AR | 16 | 3 | 6 | 4 | | | 29 |
| AZ | 1 | | | 3 | | 4 | 8 |
| CA | 1 | 1 | 5 | 5 | 6 | | 18 |
| FL | | | 1 | | | | 1 |
| GA | | | | | | | |
| NY | | | | | | | |
| OH | | | | | | | |
| TX | 1 | 4 | 5 | | | | 10 |
| OTHERS | 5 | 1 | 1 | 3 | 3 | 2 | 15 |
| TOTAL | 24 | 5 | 17 | 23 | 9 | 12 | 90 |

[a] A = Biology, Ecology, and Population Dynamics; B = Viruses, Epidemiology and Virus-Vector Interactions; C = Chemical Control, Biopesticides, Resistance Management, and Application Methods; D = Natural Enemy Ecology, and Biological Control; E = Host-Plant Resistance, Physiological Disorders, and Host Plant Interactions; F = Integrated and Areawide Pest Management Approaches, and Crop Management Systems.
[b] APHIS = USDA, Animal and Plant Health Inspection Service; ARS = USDA, Agricultural Research Service.

## I. Plenary Session Keynote Address Summaries:

### Section A: Plenary Session Summary

Jacquelyn L. Blackmer[1] & David N. Byrne[2]

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### Developmental and Behavioral Effects of Dietary Constituents on *Bemisia tabaci*

It is generally believed that nitrogen is the limiting factor for phloem-feeding insects. Not only is it present in low concentrations, but the ratio of essential: nonessential amino acids is unbalanced. Despite these apparent obstacles, phloem-feeding insects have adapted to this niche and are in fact quite successful. Whiteflies, aphids and scale insects are considered to be some of our most important agricultural and horticultural pests. Various morphological or physiological modifications (i.e., gut modifications and bacterial symbionts), as well as considerable behavioral flexibility (i.e., compensatory feeding, creation of nutrient sinks, ability to migrate) are in part responsible for their success. For *Bemisia tabaci* reared on *Euphorbia pulcherrima*, host quality significantly affected survivorship, adult weight, and flight behavior. For senescent compared to vegetative hosts, survivorship and adult weight were significantly reduced and long-duration flights were restricted to the first few days after emergence. These types of responses were examined in much greater detail in *Cucumis melo* with respect to fluctuations in amino acids. During a 12-wk study, 23 amino acids were detected, but these varied over time. For most essential amino acids ("rat 10"), there were two peaks observed, an initial large peak from wk 1-4, and a smaller peak associated with senescence during wk 10 and 11. For histidine, ornithine and citrulline, one large peak was observed from wk 5-8. Arginine peaked during the first few weeks and was no longer detectable after wk 7. Serine and glutamine/ glutamic acid were the only amino acids that peaked during visible senescence. We hypothesized that these different trends in amino acids were, at least in part, responsible for observed differences in life-history traits and flight behavior.

Multiple regressions were used to test the influence of amino acids on life-history traits of *B. tabaci*. However, to eliminate difficulties due to high intercorrelations among certain amino acids, a factor analysis using the principal extraction technique and varimax rotation was first performed. Factor analysis created a reduced number of orthogonal factors that, for the most part, corresponded to the trends that were observed for the various groups of amino acids. Factor 1 was comprised of the essential amino acids, with the exception of histidine and methionine. Factor 2 was comprised of glutamine/glutamic acid and serine. Factor 3 was predominantly histidine and ornithine; citrulline separated out as factor 5. Factor 4 was comprised of methionine and alanine, and factor 6 was comprised principally of aspartic acid. These 6 factors explained 86% of the variance among the amino acids. No single or combination of factors explained a significant amount of the variability in oviposition. For both male and female whiteflies, factor 1 was the single most important factor for explaining the variability in weights ($R^2$=0.25, $P <$ 0.005; $R^2$=0.57, $P < 0.005$, respectively). As concentrations of essential amino acids decreased, so did weights. Factors 1 and 3 were the most important factors influencing development time ($R^2$=0.54, $P <$ 0.005). As these amino acids increased in relative concentration, developmental time decreased. Percent emergence was positively associated with factor 1 and negatively associated with factor 6 ($R^2$=0.28, $P < 0.005$). These analyses reveal relationships among variables, but do not imply causality. However, a recently developed feeding chamber and artificial diet for whiteflies, will allow us to begin to test hypotheses originating from this exploratory approach.

In the context of these studies, flight behavior also was examine, and although long-distance fliers were present throughout the 12 week study, the frequency of long-distance flights significantly increased during the last three weeks ($X^2$=30.2, $P < 0.001$). Additionally, through paired comparisons of leaves with and without developing whiteflies, we were able to demonstrate that whiteflies create a nutrient sink through aggregative feeding. Total amino acids as well as several individual amino acids (Cys, Ile, Leu, Tyr, Phe, Gaba, Orn, Lys, His, Arg) were significantly elevated in leaves that contained an average of 40.4 $\pm$ 4.2 developing nymphs ($P < 0.05$). Once flowering and fruit initiation began, however, no significant differences were detectable between leaves with or without whiteflies.

### Section B: Plenary Session Summary

Jane E. Polston

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### The Appearance of Tomato Yellow Leaf Curl Virus (Geminiviridae, Begomovirus) in Florida

Tomato yellow leaf curl virus (TYLCV-Is) is a whitefly-transmitted geminivirus first described from Israel. This virus has caused economically significant yield losses in tomato in the eastern Mediterranean for many years. Much time and expense have been devoted to developing strategies for its management. For a geminivirus, the host range is broad, and includes both crop, ornamental and weed species, however tomato is the crop which is most often afflicted. Symptoms appear in tomato several weeks after inoculation and include severe stunting, marked reduction in leaf size, upward curling and chlorosis of leaf margins, mottling of leaves, and high rates of flower abscission.

In the early 1990's symptoms characteristic of TYLCV-Is were observed in Cuba, the Dominican Republic, and Jamaica (1, 2, 3, 4, 5). These symptoms were shown to be caused by a virus with a genomic sequence nearly identical to that of TYLCV-Is. It is not known how this virus came to be in Cuba and Jamaica, but in the Dominican Republic it is believed that the virus was introduced on transplants which had been purchased in the eastern Mediterranean for fruit production in greenhouses in northwestern Dominican Republic.

In July 1997 symptoms characteristic of TYLCV-Is were observed on one tomato plant in a field in Collier Co. and several tomato plants in a retail garden center in Sarasota Co. FL (7). Amplification with three sets of primers, restriction analysis of amplified fragments, and hybridization with a clone of TYLCV-Is indicated that TYLCV-Is was present in symptomatic plants. The sequence of a 1300 bp amplified fragment was 99% identical to TYLCV-Is from the Dominican Republic and 98% identical to an isolate from Israel (Gene Bank Acc. No. X15656). It appears that the virus entered the U.S. in Dade Co. Florida in late 1996 or early 1997, infected tomato plants in production for retail sale in at least two Dade Co. greenhouses, and was rapidly distributed via retail garden centers around the state. Infected plants were purchased by homeowners and in some cases the virus appeared to move from home gardens to nearby commercial nurseries and production fields.

Regulatory procedures as well as field management practices were implemented within weeks of identification in Florida to minimize the movement and incidence of this virus. Initial incidences of TYLCV-Is were low in most of the state (except Dade Co.) during the 1997-98 production season. Incidences throughout the state were significantly higher in the 1998-99 production season. Yield losses were experienced by some growers, and most growers are experiencing increases in production costs due to new practices to manage TYLCV-Is. Almost all growers are using imidacloprid in both transplants and field plants, in addition to multiple inspections to rogue infected-looking plants from fields. Pesticide applications to minimize whitefly populations have increased. New regulations have been imposed on transplant producers of known TYLCV-Is host plants, including lisianthus (*Eustoma grandiflorum*), tobacco (*Nicotiana tabacum*) and tomato, to minimize the occurrence of TYLCV-Is in certified transplants.

## Section C: Plenary Session Summary

J. R. Brazzle[1], N. Toscano[2] and P. Goodell[3]

[1] University of CA Cooperative Ext., Kern County, CA
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### Implementing a resistance management program for *Bemisia argentifolii*: Building the necessary bridges

Summarized by T. J. Henneberry

Dr. Brazzle suggested that successful management of silverleaf whitefly in the San Joaquin Valley is dependent upon IPM, resistance management and hard work. Chemical tools [particularly the use of the insect growth regulators (IGRs)] are an integral part of the whitefly management program. The efficacy of these products depends upon a good scouting program, use of the action thresholds and judicious application of each tool. A high quality program includes cultural management techniques tailored on a regional basis. In the SJV a high premium should be placed on host plant sanitation, cotton management and intensive scouting to assist in good decision making.

## Section D: Plenary Session Summary

Juli Gould.

USDA-APHIS, Phoenix Plant Protection Center.

### Evaluating the impact of whitefly natural enemies established during the classical biological control program

Classical biological control has been a very successful strategy for several species of non-native pest whiteflies. The impact of the released natural enemies on the target pest has been well documented. Designing methodologies to evaluate the impact of released parasitoids against *Bemisia* has not been easy. For this presentation I attempted to answer the question: Why was evaluating the impact of parasitoids so straightforward for other classical whitefly biocontrol programs, and why is it so difficult for *Bemisia?* Evaluations should seek to answer three questions 1) Do parasitoids reduce the average density of the pest, 2) What are the mechanisms behind density reduction, and 3) Which species are responsible for density reduction? For this presentation I concentrated on how best to determine the effect of exotic natural enemies on the average density of the target pest.

Determining the effect of natural enemies on pest species is best addressed using an experimental approach. One creates two types of populations; ones with and ones without the natural enemy. Differences in pest mortality are then correlated to the natural enemy's density and interpreted as the effect of the natural enemy. One can create with and without contrasts both in time (Before and After Contrasts) or through space (Geographic Contrasts). Because there can be variability within a site from year to year and between sites because of specific site characteristics, it is even more powerful to combine the two approaches.

Examples were presented of the successful use of with and without contrasts to demonstrate the success of biological control for seven whitefly species. Before and after contrasts were used for all seven species, with life-tables and multivariate analysis also used for a few species. With and without contrasts do not work well when the density of the pest from year to year or from site to site is highly variable and influenced by factors such as migration, changing cropping patterns year-specific weather patterns, and changing pesticide use. These factors are quite prevalent in the dynamics of *Bemisia*. One factor that contributes to this high variability is the fact that the sampling units are not stable through time. The other whitefly species mentioned are all pests of perennial plants that can be sampled through time. *Bemisia* attacks annual crops, and when sampling it is very difficult to control important factors such as proximity to alfalfa or melons and pesticide use against other pests.

To get around this problem, D'Almeida et al. used multivariate analysis to evaluate the impact of two *Encarsia* species and other biotic and abiotic factors on the spiraling whitefly (*Aleurodicus dispersus*). They claimed that "with this technique, data becomes quantitatively comparable across vast areas. In particular, the impact of a biological control agent becomes measurable in the situation of multi-cropped farmers' fields, where many factors influence host populations or yield". The results of their study for the spiraling whitefly and two mealybug species were presented. The density of nearby human populations, as well as natural enemy presence, was the most important variables predicting pest density. I would recommend designing and implementing multivariate analysis if we are going to effectively evaluate the impact of exotic parasitoids on *Bemisia* populations in the United States.

## Section E: Plenary Session Summary

### Progress in Breeding Alfalfa for Resistance to the Silverleaf Whitefly

Larry R. Teuber, Larry K. Gibbs, and Kenneth L. Taggard

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The silverleaf whitefly (*Bemisia argentifolii* Bellows and Perring) has been recognized as a serious pest in Low Desert alfalfa production since 1991. Annual losses are estimated to exceed $26 Million in Imperial County, California alone. In October 1992, we identified 73 individual plants exhibiting little if any stickiness and fewer whitefly nymphs than commercially available cultivars. During the next two production seasons evaluation procedures, estimates of genetic variance, and a plant breeding protocol were developed. Using the estimates of genetic variance we predicted that three to five cycles of selection would be necessary to develop economic resistance to the silverleaf whitefly. Selection is based on an index using subjective ratings for both stickiness and number on immature whiteflies on the foliage (both are scored on a 1=clean to 5=severe damage scale). The breeding protocol includes among-and-within half-sib family selection and a winter seed increase nursery in South America (Chile). Following four cycles of selection we have developed populations characterized by significantly reduced presence of whitefly nymphs and stickiness on the foliage. These characteristics have been incorporated into a genetic background that is adapted to hay and forage production in the Low Desert. Experimental cultivars are now in the seed increase process and we expect to have commercial seed of a cultivar available to growers in January 2001. Studies have been initiated to determine the mechanism of resistance.

## Section F: Plenary Session Summary

J. C. Palumbo, P. C. Ellsworth, T. J. Dennehy, and K. Umeda.

University of Arizona, Yuma, Maricopa and Tucson, AZ.

### A Grower Initiated Model for Sustaining Chemical Efficacy Across Commodities

During the past decade, the silverleaf whitefly in Arizonahas been relegated to a managed pest. This was achievedprimarily through the development of integrated pest management programs in cotton, melons and vegetables which promoted avoidance of whiteflies through cultural practices, use of selective insecticides, extensive sampling and monitoring protocols, and rational, prudent, and optimally-timed insecticide use. Growers in all commodities were quick to adopt and modify these management strategies as new insecticide compounds became available.

Emergency Exemptions (Section 18) for Admire® in melon and vegetables, and Danitol® in cotton, were first available to Arizona growers in 1993. However, due to excessive use, pyrethroid efficacy was significantly reduced in some growing areas by 1995. In response, the Arizona Cotton Growers Association (ACGA) requested limited use of and received an exemption for two insect growth regulators, Knack® and Applaud®. Availability of the IGRs made possible the UA Integrated Resistance Management program that promoted non-chemical management of whiteflies, in conjunction with a three-stage chemical use strategy designed to maximize the longevity of insecticide modes of action. Implementation of this program has since reduced insecticide use for whitefly management overall, and provided for recovery of pyrethroid efficacy.

Admire has provided consistent whitefly control on melons and leafy vegetables for the past six years. However, growers have recently become concerned about resistance risks associated with intensive Admire use on melons and the lack of registered insecticides with which to alternate. In 1998, the Western Growers Association (WGA) requested and received an exemption for the use of Applaud on melons in an attempt to diversify the chemistries available to control whitefly and sustain Admire efficacy. Because whitefly exposure to Applaud may soon overlap among melons, cotton and fall vegetable crops, cooperation will be needed among growers to harmonize insecticide use among commodities, to cover management needs of the respective groups, and to protect long-term Applaud efficacy.

Thus, in the spring of 1998, the leadership within the WGA and ACGA met to discuss the possibilities of developing a cross-commodity approach for managing whiteflies and sustaining long-term insecticide efficacy. A Cross-Commodity Growers Working Group was formed, and discussions focused on formulating practical pest management guidelines for cotton, melon and vegetable growers in Arizona. Participants also included representatives from the Arizona Vegetable Growers Association, Yuma Vegetable Shippers Association, Arizona Cotton Research and Protection Council, Cotton Incorporated, and Arizona Department of Agriculture. A technical working group was formed and comprised of University of Arizona research scientists and extension specialists, Arizona Department of Agriculture officials and pest control advisors from each commodity and regional growing area. This group was charged with developing insecticide use guidelines for the 1999 growing seasons, identifying potential vulnerabilities for the short-term (2-3 years), and developing long-term strategies for stabilization of chemical efficacy against whitefly and introduction of new pest management tactics.

The efforts of the technical working group have resulted in the development of a model approach to examining possible strategies for sustaining chemical efficacy in multiple cropping systems. The process involved compiling data for crop production, insecticide use patterns, and simulated whitefly population dynamics for key host crops within three distinct growing regions in Arizona, and constructing graphs that when overlaid identify important, multidimensional interactions within cropping systems. Based on the patterns resulting from our analysis, initial recommendations have been formulated to harmonize chemical use across commodities by restricting Applaud use to only once per crop season in specified use windows, with additional guidelines for reducing the possibility of exposing successive whitefly generations to the same mode of action. The diversification and limitation of alternative chemistries, such as Admire and Knack, and the refinement of cultural practices are to be considered as well. Should this model of cooperation be successful, valuable and scarce modes of action may also be shared in the future within diverse, integrated use systems.

**II. Reports of Research Progress**

## Reports of Research Progress

### Section A: Biology, Ecology, and Population Dynamics

Co-Chairs: Steve Naranjo and Rufus Isaacs

**Investigator's Name(s):** [1]C. C. Chu, [1]C. G. Jackson, [2]E. T. Natwick, [1]T. J. Henneberry, & [3]G. S. Simmons.

**Affiliation & Location:** [1]USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ, [2]University of California Imperial County Cooperative Research and Extension Center, Holtville, CA, and [3]USDA-APHIS PPQ WR, Brawley, CA.

**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** 1997 - 1998

### Selectivity of CC Trap Catches of Whitefly Adults and Whitefly Parasites *Eretmocerus eremicus* and *Eretmocerus emiratus*

Studies were conducted at Holtville, CA and Phoenix, AZ to compare silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, and whitefly parasite catches with CC traps and yellow sticky card traps in greenhouses. In the 1997 study at Holtville, CA, cantaloupe and watermelon plants were raised in three greenhouses (12.5 x 9 ft) (= three replicates) in soil-mix plastic container. The study was conducted from February to April. Five 3 x 5 inch yellow sticky card traps with both side exposed and five yellow trap base CC traps were installed in each greenhouse. Pairs of each type were placed within 50 cm apart. Whitefly adults and *Eretmocerus eremicus* were released in the greenhouses periodically. Adult whitefly trap catches and parasitized nymphs on leaves were counted. Few adult whiteflies and *E. eremicus* adults were caught in CC traps compared with yellow sticky card traps. This probably occurred because of the close proximity and competition for catches between the two trap types. In 1998, eight cloth-covered cages (8 x 8 x 8 ft) were placed in a large greenhouse. The 4 cage treatments were: no traps, 2 yellow trap base CC traps, 2 yellow sticky card traps (3 x 5 in.) with one surface exposed, and 2 yellow base CC traps plus 2 yellow sticky card traps. CC traps and yellow sticky card traps were placed 6 or more ft apart. Whitefly adults and *E. emiratus* adults were released periodically. Parasite to whitefly adult catch ratios were 6.9 and 0.5 for yellow sticky card traps and CC traps in individual cages. With the two trap types in the same cages, the parasite to whitefly adult catches were 3.5 and 0.3, respectively. Results indicate the potential of using CC traps for adult greenhouse whitefly control in combination with parasites releases for whitefly nymph control.

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**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** 1996 - 1997

## Silverleaf Whitefly Adults Caught in CC Traps at Different Trap Heights and Trap Catch Relationships to Leaf-turn Counts on Cotton

The effects of trap placement on silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, adult catches in CC traps in cotton fields were studied in California and Arizona in 1996 and 1997. In a no-choice study in 1996, more adults were caught in traps placed 15 cm below the top of the cotton canopy compared with traps placed at canopy top or 15 cm above the plant canopy. Traps caught more whitefly adults in the Stoneville 474 and Louisiana 887 plots compared with traps placed in the Deltapine 5415 and 5461 plots, reflecting the same differences in adult populations on the leaves, as determined using the leaf-turn method. In a no-choice trap study in 1997, trap catches were significantly correlated with leaf-turn counts with traps placed at the top of cotton beds, 30, 60, 90 and 120 cm above plant beds. Significant correlations occurred from 21 August to 18 September when the leaf-turn adult counts were 54 or more adults per ten leaves. In a choice study in 1997, adult whitefly trap catches from 14 August to 18 September in traps placed from 30 to 120 cm above cotton beds were significantly correlated with adult leaf-turn counts.

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**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** 1996 - 1997

## Silverleaf Whitefly Adult Catches in CC and Suction Traps Above Bare Ground and Implementation of CC Traps for Monitoring Whitefly Adult Populations in Imperial and Palo Verde Valleys in California

Fewer (20%) adult silverleaf whiteflies, *Bemisia argentifolii* Bellows and Perring, were caught in CC traps compared with suction traps. However, trap catches in the two type traps were significantly correlated. In choice and no-choice trap studies on bare ground, more adult whiteflies were caught in CC traps placed at the ground level compared to traps placed from 30 to 120 cm above ground. Year round CC trap catches averaged on a weekly basis for Imperial Valley, California in 1996 and 1997 and Palo Verde Valley in 1997, showed patterns of population fluctuation that are typical in the southwestern United States. Short term whitefly adult population fluctuations in most cases appeared due to occasional wind and rains, whereas overall fluctuations reflected seasonal temperature and host density effects. Results indicate that the CC trap may be a useful tool for monitoring seasonal whitefly adult populations in any specific period of time.

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**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** 1996 - 1997

## Attraction of Silverleaf Whiteflies to White Fluorescent and Incandescent Light Under Laboratory Conditions

Studies were conducted at the USDA-ARS Irrigated Dessert Research Station laboratory at Brawley, CA, to determine the attractiveness of fluorescent and incandescent light sources to adults of silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring. Individuals moved from a release chamber through plastic tubes to white fluorescent and incandescent light sources 1.5 ft distant from the release point. Silverleaf whitefly adults response to light under laboratory conditions was minimal at light intensities of 2 lux or less as measured by traps catches at the fluorescent light source. More adults were attracted to higher intensity compared with low intensity fluorescent light. Fewer adults were attracted to low (5 lux) intensity incandescent light compared with higher (137 lux) intensity fluorescent light when both were at the energy level of 0.3-0.4 $W/m^2$ . Minor movement of *B. argentifolii* adults occurred under dark or very low light intensity (< 2 lux) conditions. More adults were attracted to cotton and cantaloupe leaves and yellow sticky card traps adjacent to light sources (highest reflected light intensity) than to leaves and yellow sticky card traps distant from light sources (lower reflected light intensities).

**Investigator's Name(s):** [1]C. C. Chu, [2]P. J. Pinter, Jr., [1]T. J. Henneberry, [3]K. Umeda, [4]E. T. Natwick, [5]Y. Wei, [6]V. R. Reddy, & [6]M. Shrepatis.

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**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** 1996 - 1997

## Catches of Silverleaf Whiteflies, Thrips and Leafhoppers with Different Trap Base Colored CC Traps

Seven field studies in 1996 and 1997 were conducted in cotton, sugar beets, alfalfa, yardlong bean and peanut to compare insect catches in CC traps equipped with different trap base colors. The nine colors, white, rum, red, yellow, lime green, spring green, woodland green (dark green), true blue, and black, varied in spectral reflectance in the visible (400 to 700 nm) and near-infrared (700-1050 nm) portions of spectrum. Lime green, yellow and spring green were the three most attractive trap base colors for silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, and leafhopper, *Empoasca* spp. adults. The three trap base colors were moderately high in the green, yellow and orange spectral regions (490 to 600 nm), resembling the spectral reflectance curves of the underleaf of a green cotton leaf surface. True blue and white were the most attractive trap base colors for western flower thrips, *Frankliniella occidentalis* Pergande adults. Both of these trap base colors were moderate to high in the blue spectral region (400 to 480 nm).

**Investigator's Name(s):** [1]A. C. Cohen, [1]C. C. Chu, [1]T. J. Henneberry, [2]T. P. Freeman, [3]D. R. Nelson,[3]J. Buckner, [4]D. Margosan, [4]P. Vail, & [4]L. H. Aung.

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**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** 1993 and 1997

**Studies of Silverleaf Whitefly Nymphs Feeding Behavior**

Whitefly feeding is complex and includes the location of appropriate sites to probe leaves so that minor veins can be located. Nymphal stage survival of the silverleaf whitefly *Bemisia argentifolii* Bellows and Perring requires stylet penetration of the smallest veins in host plant leaves. Light and electron microscopy as well as confocal imaging have revealed that successful feeding always involves probing of no more than three xylem elements minor veins. Surface structures such as lamina trichomes and elongated epidermal cells provide cues for a first instar nymphs to initiate probing at appropriate places. A specialized saliva produces a sleeve-like salivary sheath that forms around the stylets to the minor veins. The sheaths are often sinuous and branched. Branching takes place both in the mesophyll and veins. Most of the sheath material inside the leaf is extra-cellular and in the extensive air space between spongy parenchyma cells. Only a small portion of the sheath is found inside cells, that portion being in epidermal cells. We found almost no evidence of stylet or sheath penetration into parenchyma or palisade cells. Leaf sectioning technique results suggested some feeding sheaths from the plant surface to sites other than vascular tissues. Stained and cleared non-sectional leaves provide a view of entire intact sheaths which showed that nymphs that developed beyond the first instar always made contact with veins as evidenced by the presence of the salivary sheaths. Fused bead appearing sheaths were up to 140 µm long and about 2 µm in diameter at their widest dimension. Sheaths were occasionally glued to cell walls and made contiguous contact between the plant leaf surface and veins. Some sheaths terminated blindly without reaching a vascular bundle. These were invariably sealed at the end. It appeared that successful feeding always involved intact sheaths. The relative success of silverleaf whitefly on different hosts is, in part, attributable to the geometry of the feeding arrangement in relationship to the availability of minor veins in the host plants. For example, a preferred host cantaloupe has 2X the amount of vascular bundle tissue compared with a poor host lettuce.

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**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** January 1, 1997 - December 31, 1998

## Improvements to the Artificial Feeding System for *Bemisia argentifolii*

Our goals in dietary improvement are not to bring B. *argentifolii* to adults on the artificial system, but rather to bring the greatest possible proportion to third instar within the shortest time, in order to use these larvae as hosts for parasitic wasps. However, within the last 6 months we have successfully produced at least 50 adult whiteflies on artificial feeders, having been reared through their entire development on artificial diet. To this end, we have added many different agents to the standard larval diet (5% yeast extract, 30% sucrose; Jancovich et al., 1997, Feeding chamber and diet for culture of nymphal *Bemisia argentifolii*. J. Econ. Entomol. 90: 628-633) and using standard diet as the control, have assessed changes in percentage survival and development to third or fourth instar within 13-14 days.

Slight improvement in development was observed with added alanine and with reduction of sucrose to 15%; these items will be assessed further. Marked differences were noted among batches and between manufacturers of yeast extract, Difco and BBL being the most useful. Development appeared to be similar at 27$^{o}$ or 31 $^{o}$C in the light or in the dark, but temperatures above 31$^{o}$C inhibited growth. Although development was much slower, third instar larvae were obtained on the standard Akey and Beck diet for aphids; this is the only diet other than yeast extract and sucrose which has ever permitted development of whitefly larvae beyond the first instar. We have analyzed amino acid composition of larvae reared on plants and on feeders, and have compared this analysis to yeast extract. We are basing additions of amino acids to the diet on these analyses, which technique has proven useful in diet improvements for aphids.

Major improvements have been achieved in two areas, egg sterilization including reduction in fungal contamination, and new membrane. Ten% chlorox has routinely been used to surface-sterilize eggs washed from leaves, but we have learned that substitution of the antibacterial-antifungal agent roccal appears to lead to much better percentage of hatch and improved survival.

Perhaps the greatest improvement in the rearing technique has been the adoption of an autoclavable, commercially available membrane to replace Parafilm. Filter membranes composed of Teflon are very thin, acceptable to the larvae for feeding, and the plastic screen which supports these membranes mimics the rough surface of the leaf which appears to be attractive to the larvae as well. We have now adopted these Teflon membranes for all feeders, and the ability to autoclave the entire feeder system has been a major improvement in reducing contamination. These membranes are, however, far more expensive than Parafilm (ca. $2 per membrane), but with care they can be reused at least once.

Fourth instar nymphs (red-eye) were surface sterilized and kept in sterile conditions. When adults emerged, they were moved to feeders under sterile conditions. These adults laid eggs on both Parafilm and Teflon membranes, the eggs hatched in high percentages, and the larvae matured to third and fourth instars on the feeders. These results confirm that eggs laid directly on feeders develop normally, and that materials obtained from plants via the pedicel are not necessary to the hatching and development of the larvae. This technique may prove very useful in establishing larger scale artificial rearing.

Parasitoid wasps including *Encarsia formosa* and *E. pergandiella*, but not *Eretmocerous mundus*., have been reared to adulthood on whitefly larvae on these feeders. Details are presented elsewhere.

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**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** 1998

## Whitefly Progeny Production vs. Mortality Factors: Ideas for Future Research

Research on *Bemisia* populations has been continuing for over 20 years, including about 10 years on *B. argentifolii*. We examined some of the features of *B. argentifolii* populations in order to try and point out direction for future research. Recent findings including ours and those of S. Castle showed that SLW may reach 500 or more eggs/female. Such an increase over the 100 or less eggs/female reported elsewhere is overwhelming. Here we deal with it assuming other parameters, such as generation time and adult survival do not change.

In order to maintain a steady population (zero population growth), in a closed system devoid of emigration and immigration, at 100 eggs per female, survival should not exceed 1 female – or 2% (assuming a sex ratio of 50%); in the case of 300 eggs per female this is 0.7% and for 500 eggs it is 0.4%. Therefore, the difference in percentage mortality required for achieving zero growth between 100 and 500 eggs per female is 1.6%.

Overall immature field mortality of untreated *B. argentifolii*, according to S. Naranjo and P. Ellsworth's recent findings, is between 91.5 and 99% (differences are in generations of whitefly). This is insufficient for zero population growth even at 100 eggs/female, whereas in cases with 300-500 eggs/female, it will be necessary to obtain additional 1.6% mortality over the 98% if population growth is to be checked. On the other hand, means of reducing oviposition, like adult mortality, could act synergistically with immature mortality factors such as natural enemies, to obtain the necessary control levels. Therefore, the concept should be to develop, introduce and improve a natural enemy complex in order to maintain a high level of immature mortality and augment it, while working on additional means for the reduction in oviposition rates to levels permitting immature mortality to be most effective.

We may exploit the fact that, under certain circumstances, the whiteflies do not cause outbreaks and yet, natural mortality factors do not seem to differ from those under outbreak conditions. A careful life table study leading to the understanding of these cases can enhance our chances to find ways to reduce whitefly populations. Since population buildup is contingent upon oviposition rates (natality) and upon mortality, we could examine the causes for low or high natality such as:

a) Heterogeneity in the female population: There may be "high reproduction females" (females that either live longer or lay more eggs during the same life span) causing outbreaks and "lower reproduction females" that do not cause them. This can be 1). in the same field or 2). in different fields, crops and areas.
Present information indicates that there is little support for 1). but evidence for 2). exists.

b) Plant quality characteristics: The existing evidence concerning differences in oviposition rates all points to plant quality as a determinant in whitefly development differences, but no critical experiments have been conducted to determine the rate of heterogeneity within females, especially in different geographic areas.
Moreover, relevant plant quality traits may change greatly with the season and location as indicated by differences in infestation levels of the same plant species and variety in different fields.

c) Egg quality and Sex ratio differences: This possibility would mean that numerous eggs are deposited but only some would give rise to viable females. So far, observations do not support this idea.

Plans for future action should include:

A. Continued maximal pressure on immatures by natural enemies through their introduction, augmentation and conservation coupled with careful life-table studies.

B. Exploiting and manipulating physiological and behavioral characteristics of the whitefly adults, following research concerning: a. Presence and causes for heterogeneity of adult populations, b. Physiological and behavioral changes in oviposition habits (s.*l*.) and survivorship as influenced by extrinsic factors and c. Intrinsic influences on whitefly adults such as physiology (*e.g*. oogenesis, egg fertility and flight), and behavior (*e.g.* mating host selection and oviposition).

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**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** 1998

## Comparative Host Plant Effects on the Biologies of *Bemisia and Trialeurodes*

Stage-specific development, survival, size, progeny sex ratio, and reproductive potential were measured for *Bemisia argentifolii* Bellows and Perring and two strains of *Trialeurodes vaporariorum* (Westwood). One of the two *T. vaporariorum* cultures (designated here as "A") originated from a greenhouse culture in Ithaca, N. Y.; the other (designated as "B") was colonized from a population collected locally from certain weeds, and believed at first to be a different species due to morphological differences. The *B. argentifolii* were collected locally. Host plants used were pole beans *cv* Kentucky Wonder, and cotton *cv* Sure Grow 125, initially grown in a greenhouse. The whitefly cultures, and the tests, were maintained and cultured on excised leaves placed in floral aquapik tubes filled with hydroponic solution, and maintained in large ventilated Petri dishes in an incubator kept at 25EC, 55% RH, with a 16 : 8 (L : D) h regime. Life table data revealed that host plant species had a significant effect on most biological measurements across each whitefly genotype, and the effects were generally significantly different between whiteflies reared on the same host plant. Total pre-imaginal mortality showed that cotton was a significantly better host for *B. argentifolii* (35.5% on cotton vs 59.7% on bean), while bean was a significantly better host for typical greenhouse whitefly *T. vaporariorum* "A" (20.6% on bean vs 54.8% (on cotton). The "wild" *T. vaporariorum* "B" exhibited a high mortality rate on both host plants, occurring mainly during the early larval stages. Development to adult for the silverleaf whitefly was significantly shorter on cotton (17.5 d) than on bean (22.1d). Conversely, the greenhouse whitefly "A" expressed a shorter develop time on bean (20.5 d) than on cotton (24.6 d). Host plant had no significant difference on percentage female progeny or preoviposition period of the whiteflies tested. Daily egg production was significantly affected. Silverleaf whitefly eggs per day after developing on cotton was 7.6 vs 4.5 on bean. The opposite was recorded for greenhouse whitefly "A"; *T. vaporariorum* "B" oviposition was very low (< 2 eggs per female) and not significantly different between host plants. Similarly, pupal size corresponded to the other results. These findings clearly demonstrated that green bean is a significantly better host plant than cotton for greenhouse whitefly "A", while cotton a better host for rearing silverleaf whitefly.

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**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** January - October 1998

## Occurrence and Evaluation of *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) Strains in Brazil Using PCR-RAPD

*Bemisia tabaci* (Gennadius) has become an increasingly important pest of agricultural crops world-wide, causing extensive damage through direct feeding and as a vector of many viruses. Up to 1990, only *B. tabaci* biotype A was found in Brazilian agroecosystems and it was considered a secondary pest. In 1991, a new biotype, known as the poinsettia strain, or silverleaf whitefly was detected in Brazil causing phytotoxic disorder in cucurbits and attacking weeds. In the last three years this biotype has become a serious pest of various important crops in all five regions of Brazil. In December, 1996, this insect was found present in five states of the country, presently its population spread to 17 states, in just a year and half. The losses caused by the B biotype as vector and/or pest are now over US$ 1 billion. The crops most attacked are tomatoes, watermelons, cotton, benas and soybeans. The taxonomic identity of *B. tabaci* is problematic as it is highly polymorphic with extreme plasticity in key morphological characters that vary according to the host. We used PCR-RAPD to evaluate the presence of B-biotype and/or others biotypes of *B. tabaci* that may be present in Brazil. The analysis were realized in 70 samples collected in 30 different localities on 27 different hosts including cultivated and weed plants. It was confirmed the presence of the B-type in 14 states: Alagoas, Bahia, Ceará, Distrito Federal, Goiás, Minas Gerais, Mato Grosso do Sul, Mato Grosso, Paraíba, Pernambuco, Rio de Janeiro, Roraima, São Paulo e Tocantins. In some localities both biotypes A and B were found: Jaboticabal, SP; Rondonópolis and Cuiabá, MT and Goianira, Go. It is necessary to monitor the spread and development of B biotype populations in order to adopt appropriate management strategies to control this whitefly.

**Investigator's Name(s):** Steven E. Naranjo & Thomas J. Henneberry.

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**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** January - December 1998

## Evaluation of a High-Speed Thermodetector for Estimating Cotton Lint Stickiness

Cotton lint stickiness is problematic at many post-harvest phases of processing including ginning, carding and particularly spinning. The manually-operated sticky cotton thermodetector (SCT) has been a standard research tool for assessing cotton lint stickiness. With the inevitable replacement of the SCT by several competing automated systems (e.g. High Speed Stickiness Detector [H2SD]) it is necessary for us to revisit many of our previous sampling analyses. Here we summarize comparative analysis of field samples assayed by both the SCT and H2SD systems.

**Data Collection and Assay:** Sample data were collected in a total of 18 sites in 1996 from Maricopa, AZ and Brawley, CA. Five different sample units were examined. After ginning a subsample of lint from all samples was assayed using the H2SD (3 replicate assays per subsample). Approximately one-third of the samples were also assayed using the SCT (2 replicate assays per subsample) to facilitate direct comparisons between systems.

**Sampling Distribution:** There was a difference in the within-field distribution of thermodetector spots between the SCT and H2SD. Samples assayed by the SCT typically had coefficients of variation (CV) $\leq$ 1 indicating a Poisson distribution. In contrast, a large fraction of the samples assayed by the H2SD had CV's > 1 indicating an aggregated distribution. The reasons for the striking difference between the SCT and H2SD in our samples is unknown and further detailed investigation is clearly warranted.

**Comparison of Systems and Sample Units:** Overall our samples did not provide a good range of stickiness levels. Nonetheless, there were clear differences in the total number of thermodetector spots between SCT and H2SD assays, with the latter being consistently lower. The relationship between the SCT and H2SD for our samples differed from those previously reported. In general there were no statistical differences in estimates of stickiness among the various sample units examined nor any clear pattern in levels of variability in relation to size of the sample unit. Thus, it took much longer to collect larger sample units in comparison with smaller sample units, but this extra effort was not offset by less variable estimates. Based on results to date the 1-plant sample unit is most efficient. Additional observations are currently being collected for several boll-based sample units.

**Partitioning of Variance Components:** Because thermodetector assays are conducted on subsamples from the field sample unit, the process of estimating stickiness is inherently a two-stage sampling problem with two sources of variation. We found that approximately one-third of the variation was attributable to differences among field samples while the remaining variation could be attributed to variability among SCT subsamples. This latter source of variation for the SCT includes variability due to subsampling and the SCT operator. Because the H2SD eliminates operator error we found that approximately 41% of the variability was attributed to subsampling with the H2SD system with the remaining 59% attributable to field-level variability. Taking field and assay costs into consideration our preliminary findings suggest that only one subsample should be assayed per sample unit on either machine and that more time should be devoted collecting additional sample units from the field.

**Preliminary Sample Sizes:** Taylor's power law and Iwao's patchiness regression were used to generate fixed-precision sample size functions for the SCT and H2SD systems. The much greater sample size requirements for the H2SD reflects the higher levels of between-sample variability observed for lint assayed with this system. For example, to estimate a mean stickiness level of 5 with 25% precision (SE/mean ratio) the SCT would require a sample size of 2-6 whereas 12 samples would be needed using the H2SD system. At high levels of stickiness only 1-2 samples would be required by the SCT; 4-7 samples would be needed for the H2SD.

Theoretically, an automated, high-speed system should provide the most consistent and accurate determination of stickiness, however, there are apparent problems with the H2SD system used in our studies. Further work is needed to identify and correct these problems and to assess the H2SD system on lint samples representing a broader range of stickiness levels.

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**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** June - December 1998

## Cohort-Based Life Table Studies of *Bemisia tabaci* in Cotton

Many biotic and abiotic mortality factors impact the population dynamics of *Bemisia tabaci* (Biotype B) in agricultural ecosystems, yet we have a poor understanding of the rates of these mortality factors and how they may be involved in overall population regulation. We have been using a direct observation technique to construct cohort-based life tables of *B. tabaci* on cotton in central Arizona over the past three years. These studies have identified, quantified, and compared *in situ* sources and rates of mortality of immature whitefly stages in untreated cotton plots and in plots under three different insecticide regimes (buprofezin followed by pyriproxyfen, pyriproxyfen followed by buprofezin, and a rotation of conventional materials). Here we summarize our results from a total 10 life tables completed in untreated cotton during 1997 and 1998.

Cohorts of eggs and settled 1st instar nymphs were established from natural populations in each of 4 replicate plots per generation. Four generations were observed from late June through late September in 1997 and six generations were observed from late June through late October in 1998. Each cohorts consisted of approximately 50 individuals of each stage in each plot. The location of individuals on leaves was marked with a non-toxic felt-tip pen. The fate of each individual was then tracked by visual observation with a hand lens every 2-3 days. We attempted to estimate mortality due to predation, parasitism, dislodgment, and inviability (eggs). Mortality that could not be placed into one of these categories was cataloged as unknown.

Combining all immature stages, predation by sucking predators was a large source of mortality, especially during 1997. Observed rates of predation varied from 36-51% in 1997, and 7 to 42% in 1998. A consistently large fraction of immatures were also killed by being dislodged from leaves (29-51% in 1997; 23-43% in 1998). Dislodgment likely resulted from a combination of weather (wind and rain) and chewing predation. Inviability of eggs was a large source of mortality during 3 generations over the two year (30-68%), but was minor in all other generations examined (2-17%). Parasitism by two genera of native parasitoids was a very minor source of overall immature mortality (0-4%). Survivorship from egg to adult ranged from 0.8% to 9.5 % in 1997, and 0-18.2% in 1998 suggesting a large impact of natural forces on whitefly mortality in the field. Partitioning mortality across the five developmental stages, we found that a large portion of immature mortality occurred in the egg stage (42-76% in 1997; 35-97% in 1998). Of the four nymphal stages the largest fraction of mortality consistently occurred during the 4th stadium (7-28% in 1997; 2-23% in 1998). Stage-specific rates of mortality were highest for eggs and 4th instar nymphs, reflecting, in part, the fact that these are the longest developmental stages in the life cycle. Stage-specific rates of mortality rarely exceeded 30% during any of the first three nymphal stadia; stage-specific rates of mortality frequently exceeded 50% for eggs and 60% for 4th stage nymphs. As expected from results of overall immature mortality, predation and dislodgment were consistently the two greatest sources of mortality during each individual developmental stage. The rate of parasitism in the 4th stadium approached 10% in some generations and was consistent with independent evaluations from leaf samples in the same plots. An unusual, but unknown source of mortality affected 4th instar nymphs during the 3rd generation in 1998 and contributed to 0% survivorship in that generation across all treatment plots. The posterior sections of affected nymphs were severely sunken and necrotic areas were sometime visible at the tips of developing wingbuds. Investigations are still underway to define this mortality agent.

To evaluate the relative importance of the various mortality factors we estimated rates of irreplaceable mortality for predation, parasitism, dislodgment and egg inviability. Results showed that overall, relatively little mortality from any source is completely irreplaceable. This indicates that the various mortality factors interact and readily replace one another during the five immature developmental stages. Averaged over 10 generations, 15.5% of mortality from predation, 10.4% of mortality from dislodgment, 2.2% of mortality from inviability, and <1% of mortality from parasitism was irreplaceable. K-factor and density-dependent analyses are underway.

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**Affiliation & Location:** USDA-ARS, Biosciences Research Lab., Fargo, ND; [1]Dept. Plant Pathology, North Dakota State University, Fargo, ND; USDA-APHIS, Phoenix Plant Methods Center, Brawley, CA; [3]USDA-ARS, Western Cotton Research Lab., Phoenix, AZ.

**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** 1998

## Formation of External Waxy Particles by Adult *Bemisia argentifolii* and *Semidalis flinti*

The dustywing, *S. flinti* Meinander (Neuroptera: Coniopterygidae), a predator in the southwestern USA, is active on noncrop plants (shrubs and trees) in areas surrounding agricultural areas and in urban areas, where whiteflies spend the time between crop seasons. Both larvae and adults feed on *Bemisia* eggs and nymphs. Larvae ate up to 2000 eggs during development to adults. Starved adults ate 8.5 eggs plus 8.8 nymphs per hour.

Adult whiteflies and dustywings both cover themselves with waxy particles. Whiteflies produce ribbons of waxy material, a mixture of long-chain aldehydes and alcohols, from abdominal wax plates and then use their tibia to break off the extruding ribbons to form the waxy particles which cover the insect as well as its surrounding surfaces. In *B. argentifolii* and *B. tabaci*, the major components are 34 carbons in length and in greenhouse whiteflies, *Trialeurodes vaporariorum* (Westwood), 32 carbons. Also, adult whiteflies cover their cuticular surface with mixtures of lipid classes (as do all insects).

Dustywings were collected from roses near Phoenix, AZ in 1996 and 1997, and cultured on *B. argentifolii* on cotton leaves. Dustywings also cover themselves with waxy particles from individual wax pores, located around their entire body, each of which produces two waxy ribbons with fluted edges. The end of each waxy ribbon curls back on itself to form a cylinder (particle) about one micrometer in diameter which breaks off. As extrusion continues, additional particles are formed.

Total cuticular surface lipids (including waxy particles) were composed of fatty acids (47%), alcohols (7%), hydrocarbons (20%), putative wax esters (4%) and diacylglycerols (10%); 11% remained at the origin of the TLC plate. Waxy particles alone, were composed of fatty acids (37%), alcohols (9%), hydrocarbons (19%), and diacylglycerols (13%); 20% remained at the origin. No differences in TLC lipid classes were found between males and females. No putative wax esters were detected in particles alone. The similarity in the lipid composition of the waxy particles and the total cuticular surface lipids indicated that waxy particles are the majority of the lipid on the surface of the dustywing.

Analysis by capillary gas chromatography-mass spectrometry did not detect wax esters. The major hydrocarbon was 3,7,11-trimethylheptacosane, approximately 70 ng per female and 50 ng per male. The major lipid class (approximately 65%) was the free fatty acids; approximately 1000 ng/female and 1220 ng/male. The major free fatty acid, tetracosanoic acid (24-carbon fatty acid) was 70% of the free fatty acids. Alcohols were only a minor lipid class (6%) on dustywings. The major alcohols were a mixture of 8- and 9-hydroxypentacosanes.

The whiteflies and dustywings had completely different surface chemistry. Adult whiteflies had particles of long-chain aldehydes and alcohols as well as wax esters on the cuticle surface. Dustywings did not have long chain aldehydes and very little alcohol. The major component from the dustywing as well as from the vials in which they were held was free fatty acids. They also had small amounts of methyl-branched hydrocarbons whereas whiteflies had very little hydrocarbon, either branched or straight chain.

**Investigator's Name(s):** Claudie Pavis & Nathalie Boissot.

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**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** March 1, 1997 - November 30, 1998

## Population Dynamics of *Bemisia tabaci* B Biotype, on Continuous Pumpkin Culture in Guadeloupe (French West Indies)

In Guadeloupe, as in most of the Caribbean islands, vegetable is being produced all year round. In this region, the silverleaf whitefly was first identified in 1990; it causes direct damage on melon and other Cucurbits and is responsible for PYMV transmission on tomato. We studied the causes of whiteflies outbreaks in order to manage this new situation.

Since population levels depend on the host-plant phenology, we developed a field test with the continuous presence of young, mature and senescent pumpkin plants (*Cucurbita moschata*, variety Martinica). Pumpkin is a good silverleaf whitefly host, it is easy to grow and is attained by few pests and diseases. Pumpkin plots were planted monthly in two locations of Guadeloupe, under different climatic conditions. Climatic parameters were continuously recorded. Once a week and in each location, we sampled the two most recent plots, each one consisting of 30 plants. Sampling included adult counts under 4 leaves of each plant, and adult counts on yellow sticky traps fixed at the ground level (4 per plot).

Observations during one and a half years showed that the population levels were always very low in the humid area, even outside the rain period. In the dry area, population levels were low when relative humidity was high, or when the rainfalls were frequent. However, outbreaks occurred from May to July, and corresponded to hot periods with little precipitation. These outbreaks came to an end when relative humidity and precipitation increased, although temperature remained high.

We are now focussing on sampling of parasitoids and are developing tests to evaluate the effect of environmental factors (wind, rain, relative humidity) on dispersion of whiteflies on the host-plants. This ecopathological approach is linked with the study of geminivirus transmission on tomato plants.

**Investigator's Name(s):** Thomas M. Perring[1], Judith Brown[2], Arthur D. Cooper[1], Ian Bedford[3], & Peter Markham[3].

**Affiliation & Location:** [1]Department of Entomology, University of California, Riverside, CA 92521; [2]Department of Plant Sciences, University of Arizona, Tucson, AZ 85721; [3]Department of Virus Research, John Innes Centre, Colney Lane, Norich, UK NR4 7UIL

**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** January 1, 1998 - December 31, 1988

### Genetic Analysis of *Bemisia* (Homoptera: Aleyrodidae) Populations by Isoelectric Focusing Electrophoresis

Twenty two populations of whiteflies in the genus Bemisia were screened for genetic variation at 3 allozyme loci. Ten of these 22 populations were selected for additional analysis in which a minimum of 10 enzymes representing 10 to 14 distinct loci were examined. Calculated allelic frequencies revealed three clusters among the populations examined. The first cluster was comprised of two New World populations, *B. tabaci* type A from the United States, and a *B. tabaci* type A-like population from Culiacan, Mexico. A second cluster of seven was formed from 4 Old World populations, and 3 New World populations (a population from Puerto Rico found on *Jatropha gossypifolia*, and 2 populations of *Bemisia argentifolii* (=*B. tabaci*, type B), believed to be old world in origin). A third group contained a single population from Benin that specializes on *Asystasia gangetica*. While the data support previous work with respect to taxonomic.

**Investigator's Name(s):** Michael E. Salvucci, Dawn S. Stecher, & Thomas J. Henneberry.

**Affiliation & Location:** USDA, ARS, Western Cotton Research Lab, Phoenix, AZ.

**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** January - December, 1998

### Heat Shock Proteins and Sorbitol Accumulation as Mechanisms for Thermotolerance in *Bemisia argentifolii*

The silverleaf whitefly (*Bemisia argentifolii*) thrives in hot, arid regions where daytime temperatures are sufficiently high to damage cellular machinery. Previous studies have shown that whiteflies accumulate sorbitol when exposed to temperatures in excess of about 30ºC. In the present study, experiments were conducted to determine the effectiveness of sorbitol as a thermoprotective agent and to examine the expression of heat shock proteins under conditions conducive to sorbitol accumulation. Turbidity assays and SDS-PAGE showed that sorbitol, at concentrations similar to those present in heat-stressed whiteflies, decreased heat-induced protein aggregation in cell-free extracts of adult whiteflies. Addition of sorbitol to whitefly extracts increased the thermal stability of two soluble whitefly enzymes, hexokinase and sucrase, by increasing the temperature required to inactivate enzyme activity. These results demonstrate that sorbitol is capable of protecting proteins from heat denaturation *in vitro*, consistent with its proposed role as a thermoprotectant.

Sorbitol levels in whiteflies exposed to cotton leaf temperatures of 38-41ºC (heat-stressed) were 6- to 10-fold higher than in whiteflies maintained at leaf temperatures of 25ºC (control). Northern and Western blot analyses showed that the levels of mRNA for NADPH-dependent ketose reductase (KR), the enzyme which synthesizes sorbitol in whiteflies, were considerably higher in heat-stressed compared with control whiteflies and that the amount of KR protein was slightly greater. Western blot analysis using antibodies against heat shock proteins (Hsps) showed that control and heat-stressed whiteflies contained similar amounts of Hsp70 and Hsp60 protein, and the amount of Hsp90 protein was only slightly greater in heat-stressed whiteflies. *In vivo* labeling of whitefly proteins with [$^{35}$S]Met/Cys showed that Hsp70 and Hsp90 were the major labeled polypeptides synthesized in heat-stressed whiteflies, but were only minor components of the labeled polypeptides of control whiteflies. Similar labeling profiles for Hsp70 and Hsp90 were obtained when polyA+ mRNA from control and heat-stressed whiteflies was translated *in vitro*. The results indicate that Hsp70 and Hsp90 are the major heat shock proteins in whiteflies and that their synthesis in whiteflies increases under the conditions of high temperature that induce sorbitol accumulation. That the increased rate of Hsp70 and Hsp90 synthesis in heat-stressed whiteflies did not lead to a significant increase in accumulation of these proteins suggests that the role of Hsp70 and Hsp90 in thermotolerance involves rapid turnover of these proteins rather than increases in the steady-state amounts.

**Investigator's Name(s):** Satya Vir.

**Affiliation & Location:** ARS, Central Arid Zone Research Institute, Jodhpur-342003, INDIA.

**Research & Implementation Area:** Section A: Biology, Ecology, and Population Dynamics.

**Dates Covered by the Report:** June 1991 - October 1997

## Ecology and Population Dynamics of *Bemisia tabaci* Genn (Aleyrodidae) an Extent of Damage Both by Vector and Yellow Mosaic Virus

Mothbean, *Vigna aconitifolia* (jacq.) Marechal is a drought hardy crop extensively grown in arid zone of India in an area of 1.24 million hectares with an average production of about 0, 15 million ton's. But the productivity of the crop is extremely poor (125 Kg/ha) due to heavy incidence of yellow mosaic disease and whitefly. Whitefly is by far the most serious insect and it also acts as a vector of yellow mosaic virus (YMV). Study on the biology of *Bemisia tabaci* was carried out on mothbean crop under laboratory and field conditions. Effect of thermal regime (25-40EC) on development of insect in the incubators and progression of insect under field conditions was compared. Laboratory development of the insect was completed in 28, 42 and 29 days at the three increasing temperatures of 25, 30 and 35EC, respectively. Field development of the insect was the fastest (25-27 days) during July to August and slowest (38-42 days) during December to January.

Effect of sowing dates viz. June 29, July 6, 13 and 20 revealed increase in incidence of both whitefly and YMV with delay in each sowing time. There was significant increase in the development of whitefly population in the mothbean crop sown on July 20 and its direct impact was a sharp decline in the grain yield due to poor growth of the crop. Early sown crop (June to July 6 sowing) had lesser number of whiteflies and low incidence of YMV.

Effect of mixed and intercropping of mothbean, guar and bajra was evaluated for the seasonal incidence of whitefly population and incidence of YMV. The population density of the whitefly during the peak period was 70.5 per plants on the mothbean crop, whereas the density was 44 per plant in the pure guar crop. With pearl millet, the population was 37 per plants for the mothbean and 42 for the guar crop. A similar trend of the lower population existed for the pearl millet intercropped legumes (1:1) i.e. 25 whiteflies on mothbean and 27.5 on guar crop. An incidence of the plant to plant distance from 50cm to 70 cm also reduced the incidence of the whitefly but this maneuver did not have any beneficial effect in terms of the lowering of YMV incidence.

Studies on assessment of yield data revealed that both YMV infestation and whitefly population are responsible for reduction in number of pods per plant and number of seeds per pod. The extend of yield loss due to whitefly and YMV varied from 25.57 to 73.54 in different cultivars of mothbean crop.

## Research Summary

## Section A: Biology, Ecology, and Population Dynamics

Compiled by R. Isaacs and S. E. Naranjo

Based on the submitted abstracts and recent publications, progress was made in all areas of Section A during the reporting period.

### Basic Biology and Taxonomy

The focus of mating behavior studies have been on the compatibility of different strains of *Bemisia* for cross-breeding. This has been within studies to determine the distribution and taxonomy of the different biotypes of *Bemisia* throughout the world. The karyotype of *Bemisia* was determined by European researchers, an advance that will assist with future research into *Bemisia* reproductive biology. The behavioral mechanisms of mating incompatibility remain unstudied.

There has been continued activity in the area of whitefly taxonomy based on molecular genetic typing of different populations. Recent research has shown that insects of the *Bemisia tabaci* and *Bemisia argentifolii* complex can be sorted into those from the Old World, New World and a host-race from Benin, Africa, based on this level of analysis. Further examination of this technique continues, to determine the taxonomic relationships between members of the global *Bemisia* complex.

Studies of endosymbiont-whitefly relationships are focussing on the role of *Wolbachia* in whitefly biology, after its recent discovery in *Bemisia*. This finding may have far-reaching consequences for our understanding of whitefly biology, and provide new avenues for control through disruption of whitefly reproductive biology, though the research is in its infancy.

The nutritional physiology of *Bemisia* is an active area of research that continues to reveal the many adaptations that have evolved to enable this insect to survive in environmentally harsh and nutritionally challenging environments. Biochemical studies have shown that sorbitol is synthesized during periods of increased temperature, providing a thermoprotective role against heat denaturation of proteins. The major heat shock proteins produced by *Bemisia* were identified, and shown to be synthesized and metabolized more rapidly under high temperature conditions leading to little accumulation, but greater activity. The role of amino acids in development and survival of *Bemisia* was determined for insects feeding on melon. The concentration of several amino acid was positively correlated with whitefly weight, and development. Whiteflies reared on plants of different development stages showed that the frequency of long-duration flights increased as the plants approached senescence. The impact of nitrogen fertility on *Bemisia* population dynamics and honeydew production, were investigated in cotton and showed that higher rates of nitrogen application led to greater whitefly densities and higher densities of honeydew. Research on the mechanisms of this effect, and the effects on the plant are continuing.

Development of feeding chambers for artificial rearing of whiteflies and their parasitoids has been successful. Diet modifications and changes to the hardware has provided a system that can support development of *Bemisia* whiteflies from egg to adult, and has provided whiteflies capable of supporting development of *Encarsia* parasitoids. The primary motivation is for development of an artificial natural enemy rearing system, so researchers are focussing on maximizing survival of the whitefly nymphal stages for optimal parasitoid development.

The development of an artificial feeding chamber for use with *Bemisia* will facilitate new research into whitefly physiology and behavior, and especially the role of plant nutrients and toxins in whitefly-plant interactions. This technology will be transferred to laboratories across the US, that will start using this technology, in collaboration with Dr. Davidson and colleagues in Arizona. This is expected to facilitate a number of studies that will explore fundamental and applied questions related to whitefly-plant interactions.

### Ecology and Population Dynamics

Arizona researchers continued life table studies to characterize and quantify mortality factors for immatures of *B. argentifolii* on cotton. Predation and dislodgment accounted for much of the mortality in untreated fields and survivorship from egg to adult ranged from 0-18.2% over 6 generations. Parasitism by two genera of native parasitoids was very low in all fields and never exceeded 4.0% on a generational basis. Further analyses revealed that relatively little mortality from any source is irreplaceable suggesting a strong interaction among the mortality factors that impact immature whitefly populations. Researchers in California are screening numerous perennial plants species for their potential to harbor whiteflies and serve as refugia for exotic and native parasitoids. Promising candidates include lavatera, yellow bells, chuparosa, and blue hibiscus. Texas researchers have compared stage-specific development, survival, size, sex ratio and reproductive potential of *B. argentifolii* on pole beans and cotton. Researchers in India are studying the population dynamics of whitefly and the epidemiology of yellow mosaic virus on mothbean. Delayed planting lead to larger whitefly populations and greater incidence of viral infection. Studies of the population dynamics of *B. argentifolii* on pumpkin in Guadeloupe (French West Indies) indicated that population outbreaks were associated with hot and dry conditions. Researchers in Italy examined host preference and reproductive performance of *B. argentifolii* on 18 weeds species. *Sonchus oleraceous* and *Solanum nigrum* were the most preferred host plants for adult whiteflies and positive rates of population growth were documented for 10 weed species. *S. nigrum* was identified as a reservoir of tomato yellow leaf curl virus in southern Spain. Researchers in Costa Rica have demonstrated that the use of living ground covers (perennial peanuts, cinquillo, and coriander) reduces colonization of adult whiteflies and lowers the incidence of Tomato Yellow Mottle Virus when whitefly populations are low to moderate in size.

There has been relatively little new activity in the development of sampling methods and action thresholds on any host crop. Based on a multistate study, action thresholds of 5-10 adult whiteflies per leaf were associated with the greatest net returns for cotton in Arizona and California. Work continued on evaluation of a reusable trap for capturing adult whiteflies. Researchers in Arizona and California examined capture in relation to trap color and height of trap placement within the crop canopy in cotton and several other affected crops. Results indicate that lime green, yellow and spring green were the most preferred color for whiteflies. Further work showed that the reusable trap was more attractive to whitefly than to *Eretmocerus* parasitoids in cotton. Additional work on sampling and action thresholds for other affected crops is urgently needed.

Arizona researchers continued development of sampling methods for cotton lint stickiness. Comparative evaluations of manual and high speed cotton stickiness thermodetector revealed differences in performance. Fewer sticky spots are counted with the automated systems and preliminary results suggest that counts are more variable compared with the manual system. These finding have important implications for the development of measurement scales for stickiness and the number of samples that would need to be collected for the precise estimation of stickiness. The production of a technical bulletin summarizing the sticky cotton problem and highlighted current research efforts is ongoing. This technology transfer activity will provide growers and industry with important information on one of the most serious issues facing the cotton industry today.

Version 1 of a temperature-dependent, site-specific population dynamics model of *B. argentifolii* in cotton and cantaloupe was completed by researchers in Arizona. The model is built on a flexible platform and enables users to specify many of the biological parameters of the system. Additional refinements, enhancements and field validation are needed to improve the utility of the model for predicting whitefly population dynamics under various management regimes. Many of the studies summarized above provide useful data that could be integrated into the model.

Studies of the dynamics of whitefly and parasitoid dispersal have continued in Arizona field crops. The vertical distribution of whiteflies taking off from melons was quantified, showing exponential decrease in aerial density with height. The role of weather variables in the movement of whiteflies into the upper traps in this study showed that temperature had the greatest effect on whitefly elevation. Plant senescence has been shown to increase the frequency of long-duration migratory flights. Dispersal by whitefly parasitoids is being quantified in both laboratory and field experiments, with the aim of understanding their capacity for movement from refuges into crop areas and movement between sequential crops. Immunological markers have been developed for use in parasitoid dispersal studies, and field trials of this technique are ongoing. This research has important applications to the deployment of biological control against whiteflies in field crops.

**Note:**
In addition to the studies summarized above, advances in the identification of wax composition and whitefly hormonal changes during development have been made, though these are outside the specific objectives of Section A.

**Table A. Biology, Ecology, and Population Dynamics.**

| Research Approaches | Year 1 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Determine life cycle vulnerabilities (life tables)[a], population development and natural mortality factors, natural enemies on major crops, urban plantings, weeds and predict overwintering potential.** | Whitefly and natural enemy sampling in cultivated crops, urban planting and weed hosts. | X | | Partial life table analyses have been completed for *B. argentifolii* on cotton in Arizona. Natural forces, including predation and dislodgment are major mortality factors; parasitism was a minor source of mortality. Survivorship from egg to adult ranged from 0-8.5% over 4 generations in sprayed and unsprayed fields. Studies on wild host crops in Israel indicate that parasitoids may contribute to low levels of whitefly on lantana. Whitefly and natural enemy populations were monitored in cropping systems in the Imperial and San Joaquin Valleys of California, Maricopa, Arizona and the Rio Grande Valley of Texas. The spread of *B. argentifolii* is being documented in Brazil. Life table studies provide valuable quantitative information on sources of whitefly mortality; surveys define the temporal and spatial dynamics of pest and natural enemy populations. This information is critical in developing and refining more biologically-based management systems. |
| **Develop sampling methodology, action and[b,c] economic thresholds for all major crops. Sampling methods and thresholds modified in light of natural enemy levels and existing management strategies.** | Initiate whitefly to identify spatial and temporal distributions in major cultivated crops. | X | | Relationships between whitefly density and the occurrence of tomato irregular-ripening as well as preliminary sampling plans for whitefly on tomato have been developed. Evaluations of a reusable trap for surveying adult whiteflies in various crops are continuing. Studies of the effects of various insecticides on whitefly natural enemies are ongoing. Sampling plans and action thresholds are still needed for a number of affected crops. |

**Table A. Biology, Ecology, and Population Dynamics. (Continued)**

| Research Approaches | Year 1 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Develop population models to describe and predict whitefly population growth and spatial and temporal distribution. Develop simple day-degree sub-models for estimating phenology and temporal patterns of whitefly, natural enemies and host crops.** | Summarize whitefly biology, ecology and plant phenology to identify whitefly host plant interfaces. | X | | Development of large-scale temporal and spatial models and temperature-dependent, site-specific population dynamics models continues. Such models have the potential to encapsulate our current knowledge and provide a framework for developing more efficient management systems. However, considerable biological and ecological detail, as well as information on various aspects of pest management is available and needs to be integrated into these models to make them most useful as exploratory tools. |
| **Develop sampling methods for quality of cotton lint, vegetables and other commodities.** | Initiate sampling of seed cotton in the field during the season, at harvest, after picking, moduling and ginning. | X | | Research has characterized the temporal distribution of honeydew deposition by *B. argentifolii* in cotton, improved our understanding of the relationship between lint stickiness and whitefly abundance and compared the production of trehalulose and melezitose between nymphs and adults. Studies reveal that cotton lint stickiness is randomly distributed in cotton fields. Preliminary sampling plans have been developed for estimating pre-harvest cotton lint stickiness. Stickiness constitutes one of the most important problems currently facing the cotton industry. |
| **Quantify whitefly and natural enemy dispersals and contribution to population dynamics.** | Review and analyze existing knowledge of whitefly dispersal. | X | | Studies have characterized the aerial distribution of whiteflies dispersing from cantaloupe fields and have examined the trade-offs between oogenesis and flight activity. Studies on whitefly parasitoid dispersal are ongoing. Understanding and predicting the timing and extent of the movement of whiteflies and their natural enemies is an important component in developing areawide management systems. |

**Table A. Biology, Ecology, and Population Dynamics. (Continued)**

| Research Approaches | Year 1 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Define mating behavior, reproductive isolation, species, biotypes.** | Initiate studies on mating, oviposition and other behavior. | X | | Surveys worldwide continue to document the spread of *B. argentifolii*. Electorphoretic analyses demonstrate the presence and extent of this pest in throughout Australia and Brazil. *B. argentifolii* appears to be displacing *B. tabaci* Biotype A in Brazil and is having a large impact on agricultural production through direct feeding and geminivirus transmission. Reports of heterozygotes between *B. argentifolii* and the extant Australian type *of B. tabaci* corroborates previous laboratory and highlight the taxonomic challenges within the *Bemisia* species complex. |
| **Validate *Bemisia* taxa morphology, genetic, biochemical, and biology characteristics.** | Continue examination of *Bemisia* sp. for distinct morphological character differences. | X | | Comparative morphological analyses have been completed on *Bemisia* pupae from around the world. Several of these characters are highly variable among populations suggesting that pupal morphology should not represent the sole criteria for classifying individuals within the *Bemisia* species complex. |
| **Define role of endosymbionts in metabolism, host adaptation, nutrition and survival.** | Identify endosymbionts in whitefly. | X | | The effects of antibiotics on the biology of *B. argentifolii* have been examined. Several antibiotics that interfere with bacterial protein synthesis affected growth and development of immatures, but none affected oviposition rates or sex ratio. Results have important implications for the use of antibiotics to disrupt the function of whitefly endosymbionts and other associated microbes as potential control methods. |

| | | | |
|---|---|---|---|
| **Characterize nutrient uptake and metabolism** | Determine the process of uptake and metabolism of carbohydrates, amino acids and other nutrients. | X | High levels of a polyol, sorbitol, were associated with elevated ambient temperatures.  Sorbitol may function as a thermoprotectant in whiteflies that enables them to thrive in desert environments. The pathway of sorbitol synthesis and degradation in *B. argentifolii* is unique and may offer and avenue to develop transgenic plants which could disrupt sorbitol synthesis and compromise the whiteflies ability to deal with heat stress. |

**Table A. Biology, Ecology, and Population Dynamics. (Continued)**

| Research Approaches | Year 1 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Develop whitefly artificial diets and natural enemy mass-rearing.** | Identify whitefly nutritional components in plant tissue. | X | | An artificial diet and feeding system for rearing immatures of *B. argentifolii* has been developed. Rates of development of individual instars were comparable to those estimated on various host plants. The feeding system has proven to be a useful bioassays for examining diet components and for studies of primary metabolism based on defined diets, and has the potential to provide a means of mass rearing whitefly parasitoids. |

[a] Natural enemy research complements from Section D, see Table D.
[b] Action and economic thresholds also apply in Section C, see Table C.
[c] Sampling technology applicable to all other sections, see Tables B to F.

**Table A. Biology, Ecology, and Population Dynamics.**

| Research Approaches | Year 2 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Determine life cycle vulnerabilities (life tables)[a], population development and natural mortality factors, natural enemies on major crops, urban plantings, weeds and predict overwintering potential.** | Determine potential of intercrop weed host & urban planting, movement of whiteflies and natural enemies. | X | | Life table studies continued to characterize and quantify mortality factors for immatures of *B. argentifolii* on cotton. Predation and dislodgment accounted for much of the mortality in untreated fields and survivorship from egg to adult ranged from 0-18.2% over 6 generations. Several perennial plants species show potential to serve as refugia for exotic and native parasitoids. Life history and reproductive potential has been studied on various crop and weed hosts in the US and Italy. Whitefly population dynamics and virus incidence has been examined in cropping systems in Costa Rica, India and Guadaloupe. These ecological and biological studies form the foundation of effective pest management strategies. |
| **Develop sampling methodology, action and[b,c] economic thresholds for all major crops. Sampling methods and thresholds modified in light of natural enemy levels and existing management strategies.** | Analysis and identification of needed additional sampling research to develop appropriate sampling protocol. | X | | A multistate study determined action thresholds for cotton in Arizona and California. Evaluations of a reusable trap for surveying adult whiteflies in various crops are continuing. Studies of the effects of various insecticides on whitefly natural enemies are ongoing. Sampling plans and action thresholds are still needed for a number of affected crops. |

**Table A. Biology, Ecology, and Population Dynamics. (Continued)**

| Research Approaches | Year 2 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Develop population models to describe and predict whitefly population growth and spatial and temporal distribution. Develop simple day-degree sub-models for estimating phenology and temporal patterns of whitefly, natural enemies and host crops.** | Begin model development to include all biological and plant phenology data in simulation development. | X | | The first version of a temperature-dependent, site-specific population dynamics model of *B. argentifolii* in cotton and cantaloupe was completed. Additional refinements, enhancements and field validation are needed to improve the utility of the model for predicting whitefly population dynamics under various management regimes and environmental conditions. In general, considerable biological and ecological data are available and need to be integrated into these models to make them most useful as exploratory tools. |

**Table A. Biology, Ecology, and Population Dynamics. (Continued)**

| Research Approaches | Year 2 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Develop sampling methods for quality of cotton lint, vegetables and other commodities.** | Based on year 1 results, expand and repeat sampling protocols as described. | X | | Comparative evaluations of manual and high speed cotton stickiness thermodetector revealed differences in performance that have important implications for the development of measurement scales for stickiness and the number of samples that would need to be collected for the precise estimation of stickiness. Research on quality-related problems in other affected crops is needed. |
| **Quantify whitefly and natural enemy dispersals and contribution to population dynamics.** | Validate times of whitefly dispersal, environmental factors and identify modifying factors. | X | | Studies on whitefly and parasitoid dispersal are ongoing in the desert southwest. Understanding and predicting the timing and extent of the movement of whiteflies and their natural enemies is an important component in developing areawide management systems. |
| **Define mating behavior, reproductive isolation, species, biotypes.** | Define interspecies interbiotype mating interactions. | X | | Research continues on the role of reproductive isolation in the formation of species and biotypes, using insects from around the globe. There has been little detailed study of mating behavior *per se*, and its relevance for mating incompatability. |
| **Validate *Bemisia* taxa morphology, genetic, biochemical, and biology characteristics.** | Develop genetic molecular level and acceptable species level separation. | X | | Molecular characterization of the global whitefly complex is ongoing to clarify the taxonomic relationships between *Bemisia* whitefly populations. The whitefly karyotype has been determined and is an important development in our understanding of whitefly reproduction. |
| **Define role of endosymbionts in metabolism, host adaptation, nutrition and survival.** | Determine role of endosymbionts in whitefly biological functioning. | X | | The discovery of *Wolbachia* endosymbiotic bacteria in whiteflies is a new development that has significant implications for development of control strategies targeting the reproductive biology of whiteflies. |

**Table A. Biology, Ecology, and Population Dynamics. (Continued)**

| Research Approaches | Year 2 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Characterize nutrient uptake and metabolism** | Determine the biochemical pathways for metabolism of compounds essential for whitefly development. | X | | Fndamental questions about the nutritional physiology of whiteflies are being answered with the aid of artificial diets. Biochemical pathways for carbohydrate metabolism and polyol synthesis have been determined. Metabolism of plant toxins is being studied to assesss the ability of *Bemisia* to detoxify plant deterrent compounds. The role of nitrogen fertilization in whitefly-cotton interactions was determined in field trials. |
| **Develop whitefly artificial diets and natural enemy mass-rearing.** | Develop whitefly artificial feeding systems. | X | | Development of an artificial feeder for whiteflies that will support development from egg to adults has been successful, and improvements continue to increase the proportion of *Bemisia* adults produced. This system has been tested for its effectiveness at supporting parasitoid wasp development, and adult *Encarsia* have been successfully produced in this system. Further research is needed to optimize the system for both whitefly and parasitoid development. |

[a] Natural enemy research complements from Section D, see Table D.
[b] Action and economic thresholds also apply in Section C, see Table C.
[c] Sampling technology applicable to all other sections, see Tables B to F.

## Reports of Research Progress

### Section B: Viruses, Epidemiology, and Virus-Vector Interactions

Co-Chairs: Robin N. Huettel and Bob Gilbertson

**Investigator's Name(s):** Hamed Doostdar, Moshe Inbar, & Richard T. Mayer.

**Affiliation & Location:** U.S. Horticultural Research Laboratory, USDA, ARS, 2120 Camden Rd., Orlando, FL 32803-1419.

**Research & Implementation Area:** Section B: Viruses, Epidemiology, and Virus-Vector Interactions.

**Dates Covered by the Report:** January 1 - December 31, 1998

### Effects of Tomato Mottle Virus Infection on Tomato Root Development

The effects of tomato mottle virus infection on the root development of tomato seedlings, *Lycopersicon esculentum* was investigated. Individual tomato seeds were planted in pots containing Metro Mix potting mixture containing no fertilizer. Pots were watered with 50 ml solutions of; A) fertilizer (9:45:15; N:P:K; 3.2 g/L); B) KeyPlex 350DP (5 ml/L); C) fertilizer + KeyPlex 350DP; at planting and then every two weeks for the duration of the experiment. Plants were separated into three sets (5 plants of each treatment per set), placed into enclosed cages and maintained in an environmental chamber at 26EC, 45% humidity and 12 h light/dark cycle. At the four leaf stage (three weeks after planting) 300 virus-free adult whiteflies, *Bemisia argentifolii* (WF) were introduced in to one of the cages (SET 1), the same number of viruliferus WF were added to the second cage (SET 2), and the third cage was maintained WF-free (SET 3). Plants were watered every other day with 50 ml of water during the course of the experiment. Three weeks post infestation visual symptoms of virus infection were detected in some of the plants, at which time the experiment was terminated. Plants were carefully removed from the pots, cleaned and the shoot and roots were weighed. Root and leaf samples were collected and the levels of chitinase, \$-1,3-glucanase, peroxidase, lysozyme, and total phenolics were determined. No significant variation in the shoot weights (18 ± 1.3 g) was observed for the three SETs of treatment A plants. However, virus-infected plants in this treatment showed a 70% ($P < 0.01$) root loss compared to the other two SETs. Due to the lack of fertilizer the average weights of the shoots of treatment B plants were significantly less than those of treatment A (6.8 ± 0.3 g), but virus infected plants showed no reduction in root weights compared to plants from the other two SETs. Virus infected treatment B plants showed no visual signs of virus infection. Treatment C plants, exhibited only slight viral symptoms. The average weights of the shoots of treatment C plants (16.4 ± 1.1 g) were comparable to those of treatment A. But, the plants exposed to virus exhibited only a 38% reduction in root weight ($P < 0.01$) compared to the other two SETs. The levels of defensive proteins and total phenolics varied considerably in the roots and leaves depending on treatment and WF exposure. However, in all three SETs of both treatments B, and C, The level of root \$-1,3-glucanase activity was significantly higher compared to plants in treatment A.

These results indicate that tomato mottle virus infection has an adverse effect on root development in tomato plants causing eventual severe decline and epinasty in infected plants. Addition of specific micro-nutrients (KeyPlex 350DP) to the soil appear to reduce this effect and allow the plants to tolerate infection.

**Investigator's Name(s):** Dale B. Gelman[1], Michael B. Blackburn[1], Jing S. Hu, & Jo-Ann Bentz[2].

**Affiliation & Location:** [1]Insect Biocontrol Laboratory, ARS-USDA, Beltsville, MD; [2]Floral and Nursery Plants Research Unit, ARS-USDA, Beltsville, MD.

**Research & Implementation Area:** Section B: Viruses, Epidemiology, and Virus-Vector Interactions.

**Dates Covered by the Report:** 1998

## Characterization of Fourth Instar Greenhouse Whiteflies, *Trialeurodes vaporariorum* Developmental Markers and Ecdysteroid Fluctuations

A system of markers was devised to characterize the development of fourth instar *T. vaporariorum*. Measurement of body depth combined with size and color of the developing adult whitefly eye were used to divide the instar into ten stages. When reared on salvia, tomato or sunflower at LD 16:8 and 26.1°C, body thickness of 4th instars increased to reach a maximum of 0.3-0.02 mm in stage-5 larvae. Adult eye development was first observed at stage 6. The eye which previously had been a pinpoint became slightly diffuse. At stage 7, the eye was more diffuse and at stage 8, it became the bipartite solid red structure typically associated with the 'pupal' stage. Ecdysteroid (molting hormone) levels of methanolic extracts of whitefly homogenates were determined by radioimmunoassay. The range of detection of the assay was 50-5000 picograms. Ecdysone, 20-hydroxyecdysone, 26-hydroxyecdysone, 20,26-dihydroxyecdysone and makisterone A had a high affinity for the antiecdysone antibody and thus, could be detected readily. In extracts prepared from whole body homogenates of between 15 and 55 whiteflies, ecdysteroid was undetectable. It was expected that ecdysteroid titers would have peaked in stage-5 insects, just prior to the onset of adult development which had been observed to occur at stage 6.

Histological studies suggested that apolysis (the separation of the larval cuticle from the epidermis) probably occurs after the whitefly body has grown to maximum thickness and just prior to the beginning of eye development, i.e., in stage-5 4th instars. Typically, in preparations of stage 6 or older 4th instars, the larval cuticle was either separated from the epidermis or had become detached during processing. Thus, apolysis, had probably occurred prior to this stage. In addition, in stage-6 4th instars, the wing buds were observed to have undergone considerable development, i.e., folding. By stage 7, spines were observed on the new cuticle, indicating that adult cuticle was well-formed by this stage. Results for *Bemisia argentifolii* 4th instars were similar.

**Investigator's Name(s):** Wayne Hunter, Anand Persad, Moshe Inbar, Hamed Doostdar, & Richard T. Mayer.

**Affiliation & Location:** U.S. Horticultural Research Laboratory, USDA, ARS, 2120 Camden Rd., Orlando, FL 32803-1419.

**Research & Implementation Area:** Section B: Viruses, Epidemiology, and Virus-Vector Interactions.

**Dates Covered by the Report:** January 1 - December 31, 1998

## Geminivirus-Mediated Interspecific Competition Between Whiteflies and Other Insects

This study examined the possibility of an induced response caused by a Begomovirus infection, and its effect on the systemic acquired response due to whitefly feeding. The combined interaction of whitefly feeding and virus infection of the host plant may provide a biologically significant advantage to whiteflies over other insect herb-ivores trying to utilize the same resources. The effects of an induced plant response by the infection of the Begomovirus tomato mottle virus, ToMoV, in tomato, on the feeding and development of the corn earworm, *Helicoverpa zea*, the leafminer *Liriomyza trifolii*, and the whitefly, *Bemisia tabaci* (Gennadius), B-biotype, are reported. Corn Earworm: The relative growth rate of *H. zea* larvae, late second instar, was significantly reduced when fed on leaves from the treatment of whitefly-infested, virus-infected tomatoes. However, *H. zea* growth rate was not significantly different when fed on either treatment of leaves from non-infested, virus-free tomato, versus whitefly-infested, virus-free tomato. Virus infection of the host plant appeared to negatively affect herbivore competition, producing conditions unfavorable to *H. zea*. Observations suggested that *H. zea* larvae consumed more of the virus-infected leaf material than those fed leaves from virus-free plants. This may have been due to the reduced quality of the food source. Whitefly: Oviposition was recorded on all three treatments, on newly emergent leaves of plants on days 10 and 30 postinfestation. At the 10 d sampling, there were significantly more eggs oviposited on the control treatments than on plants which had both a whitefly-infestation and virus-infection. At 30 d there were significantly more eggs oviposited on the control plants, over both other treatments, but there was no significant difference in the number of eggs produced between either treatment which had a whitefly infestation on tomato, whether the plants were virus-free, or virus-infected. There was an overall reduction in eggs oviposited on older plants regardless of treatment. Leafminer: Acceptability to leaf miner, *Liriomyza trifolii*, was based on oviposition and feeding punctures/$cm^2$ recorded on leaves of tomato, *L. esculentum* at 30 days post whitefly infestation. This was conducted in a random choice experiment in a growth chamber. There was a significant difference among all three treatments in the number of oviposition and feeding punctures with the greatest number recorded on the non-infested, virus-free tomatoes (465 punctures, q-value = 6.761, *P* = 0.000), next on the whitefly-infested, virus-free tomatoes (125 punctures, q-value = 11.940, *P* = 0.000), with the lowest number recorded on the whitefly-infested, virus-infected tomatoes (31 punctures, q-value = 3.395, *P* = 0.003) (%= 0.05). PR-Proteins: Of the PR-proteins measured, peroxidase, lysozymes, glucanase, and phenolic acid, only peroxidase showed a significant increase with time. Plant tissues were sampled on days 10, 20, and 30 post whitefly infestation. The relative mean concentration (delta $A_{550}$/min/g tissue) for levels measured in the controls, non-infested, virus-free tomatoes, showed low constant levels for samples taken on day 10, and 20, with a small, but significant increase on day 30, which was approximately double the previous levels. Levels from the whitefly-infested, virus-free tomatoes, showed a significantly greater level on day 10, approximately three-times the levels of the control and almost twice that of the other treatment (whitefly/virus), but levels dropped when sampled on day 20 becoming comparable to the control plants. However, on day 30 peroxidase levels were again significantly highest among all treatments increasing approximately three-fold previous levels. The treatment of whitefly-infested, virus-infected tomatoes, showed significantly different levels on day 10 being between the levels of the other two treatments, the control being the lowest. On day 20, levels were significantly greater being approximately twice the level at day 10, and this level was maintained to sampling on day 30. The relative mean concentration of phenolic acid (microgram Tannic acid equivalent/ g dry tissue) present in *L. esculentum*, showed an age effect. There was a significant drop in phenolic acid levels across all treatments when sampled on day 20, levels remained at this reduced level through to the last day sampled. The relative mean concentration of lysozyme (delta $A_{550}$/min/g tissue) in *L. esculentum* sampled on days 10, 20, and 30, showed no significant difference in lysozyme levels. The relative mean concentration of Beta-1-3-glucanase (micro-mol Glc/min/microgram tissue) present in *L. esculentum* sampled at 10, 20, and 30 days showed slight variations, but were not significantly different among treatments over time.

**Investigator's Name(s):** L. P. Sharp, Y. M. Hou, E. R. Garrido-Ramirez, P. Guzman, & R. L. Gilbertson.

**Affiliation & Location:** Department of Plant Pathology, University of California-Davis, Davis, CA 95616.

**Research & Implementation Area:** Section B: Viruses, Epidemiology, and Virus-Vector Interactions.

**Dates Covered by the Report:** January 1 - December 31, 1998

## Synergistic Interactions Among Components of Whitefly-Transmitted Geminiviruses

A replication-competent Begomovirus (whitefly-transmitted geminivirus) DNA-A component (referred to as chino-A) was cloned from tomatoes with symptoms of chino del tomate disease from Sinaloa, Mexico. The role of chino-A in chino del tomate disease was investigated by co-inoculating chino-A alone or in combination with the cloned DNA components of two tomato-infecting begomoviruses, pepper huasteco (PHV) and tomato leaf crumple (TLCrV), into Nicotiana benthamiana, tomato, and pepper plants. The chino-A component alone was not infectious. In combination with PHV, chino-A was infectious in all three hosts, and plants infected with this combination had more severe symptoms than plants infected with PHV alone. Furthermore, the symptoms in tomato and N. benthamiana plants infected with PHV+chino-A were similar to those associated with chino del tomate disease. In combination with TLCrV, chino-A was infectious only in N. benthamiana and no increase in symptom severity was observed. Together, these results demonstrate a novel synergistic interaction between chino-A and PHV, and provide evidence that chino del tomate disease may be caused by a complex of geminivirus components.

**Investigator's Name(s):** Cica Urbino[1], Marie-Line Caruana[2], Nicolas Sauvion,[1] & Claudie Pavis[1].

**Affiliation & Location:** [1]INRA, Unit de Recherches en Productions Vegetales, F-97170 Petit-Bourg, Guadeloupe (F.W.I.), [2] CIRAD-FLHOR, same location.

**Research & Implementation Area:** Section B: Virus Diseases, and Virus-Vector Interactions.

**Dates Covered by the Report:** January 1, 1997 - November 30, 1998

## Potato Yellow Mosaic Virus (PYMV) on Tomato in Guadeloupe: Characterization of the Virus and its Vector

Since 1989 in Guadeloupe, tomato fields have been infested by a geminivirus disease. At the same time, severe whitefly outbreaks were recorded.

Four viral isolates were collected and maintained in greenhouse by vector then grafting to tomato in order to conduct a biological (graft, mechanical and vector transmission, host range) and molecular (PCR, RFLP, hybridization) characterization of the virus. The viral isolates were transmitted by stem grafting to tomato, tobacco, datura, potato and sweetpepper. Mechanical and vector transmission were obtained on tomato. Cloning and sequencing of an isolate (Polston *et al*., 1998) led to the identification of a bipartite geminivirus already known as potato yellow mosaic virus in Venezuela, Trinidad, and Puerto Rico.

The vector was identified as *Bemisia tabaci* B biotype, using isoenzyme (esterases) electrophoresis, PCR and silverleaf symptom induction. Virus transmission studies showed that in the population raised in the laboratory, 25% of adults transmit the virus from tomato to tomato. Female are twice more efficient than males.

Field experiments revealed that yield losses caused by PYMV reach 40% on a susceptible variety when 4 week-old tomato plants were infected and could be higher if plants were younger. No yield loss occurred on 9 week-old inoculated plants. The use of pesticides to reduce the vector population did not allow to limit the spread of the disease in fields with high viral pressure conditions.

Specific tools as primers and probe are now developed for the detection of PYMV. They will be used to determine the virus reservoirs in natural conditions and to evaluate the level of resistance in tomato genotypes. Cloning and sequencing of viral isolates are in progress to estimate the variability of the virus in Guadeloupe.

Polston J. E., D. Dubois, G. Ano, F. Poliakoff & C. Urbino, 1998. *Plant Disease*, 82 (1): 126.

## Research Summary

### Section B: Viruses, Epidemiology, and Virus-Vector Interactions

Compiled by R. Gilbertson

B.1. Identification and characterization of new or emerging whitefly-transmitted viruses and strains.

*Bemisia tabaci* and *B. argentifolii* are vectors of numerous geminiviruses as well as at least one closterovirus, lettuce infectious yellows. In terms of economic importance, the geminiviruses are presently the most important group of plant viruses transmitted by these whitefly species. Interestingly, *B. argentifolii* is a particularly inefficient vector of LIYV, and the displacement of *B. tabaci* by *B. argentifolii* in southern California has led to a striking reduction in the incidence of LIYV.

The Geminiviridae family comprises a group of viruses that possess single-stranded DNA genomes and a unique twinned icosahedral virions. It has been previously noted that geminiviruses can be subdivided into three subgroups on the basis of insect vector, plant host and genome properties. Thus, subgroup I geminiviruses are leafhopper-transmitted, infect monocot hosts and possess a monopartite genome. Subgroup II geminiviruses are leafhopper-transmitted and possess a monopartite genome, but infect dicot hosts. Subgroup III geminiviruses are whitefly-transmitted, infect dicot plants and most members possess a bipartite genome composed of two similarly sized DNAs referred to as DNA-A and DNA-B. One notable exception is tomato yellow leaf curl geminivirus, which is subgroup III geminivirus that is whitefly-transmitted and infects dicots but posesses a monopartite genome. Recently, the nomenclature of this group of viruses has been changed such that the subgroup designations have been changed to genera, with the genus names derived from the type member of each subgroup. This is summarized below:

Family Geminiviridae
Genus Mastrevirus (old subgroup I; from maize streak geminivirus)
Genus Curtovirus (old subgroup II; from beet curly top geminivirus)
Genus Begomovirus (old subgroup III, from bean golden mosaic geminivirus)

The most significant development in the virus area has been the introduction of TYLCV into Florida. TYLCV was introduced into Florida in 1997, and it has rapidly spread throughout the state. The rapid spread of the virus has been associated with infection of transplants in nurseries. In the field, the incidence of TYLCV has been correlated with high populations of whiteflies. Extensive efforts are underway to determine the host range of TYLCV, and it has been detected in Lisianthus, petunia and common bean. Because Florida has a significant petunia transplant industry, TYLCV could have a significant impact on export of petunias to other states.

A second interesting finding was the presentation of evidence that a complex of geminivirus components, derived from two different begomoviruses, can cause more severe disease symptoms than one of the viruses alone. This synergistic interaction involved three geminivirus DNA components that were cloned from tomato plants with chino del tomate disease (pepper huasteco geminivirus [PHV] DNA-A and DNA-B and another distinct DNA-A component, chino-A). Disease symptoms induced in three hosts (*Nicotiana benthamiana*, tomato, and pepper) by PHV plus the chino-A were much more severe than symptoms induced by PHV alone. These results establish that (i) chino del tomate disease may be caused by a complex of geminivirus components, (ii) that complexes of geminivirus components can dramatically influence disease symptom expression and (iii) that identification of geminiviruses based on disease symptoms alone is difficult.

B.2. Molecular epidemiology: Identification of economic viruses, plants, and reserviors, and determination of geographic distribution of viruses.

Molecular tools are being used to study how TYLCV survives in the Dominican Republic during the three month whitefly host-free period. Using a polymerase chain reaction test to determine the relative contamination of whiteflies with TYLCV, it was found that by the end of the tomato-growing season, TYLCV was readily detected in whiteflies collected from all tomato fields tested. However, within one month of the implementation of the host-free period, the amount of virus detected in whiteflies collected from plants surrounding tomato fields decreased tremendously. By the end of the host free period, little or no virus was detected in whiteflies. These results suggest that whiteflies themselves are not likely to be the primary way in which the virus survives during the host-free period. Weeds and other plants in and around fields during the host-free period were then collected and tested for TYLCV using PCR. A number of weeds were found to be symptomless carriers of TYLCV. These results suggest that such symptomless hosts may be the primary way that the virus survives during the host-free period.

B.3. Virus-vector interactions, factors affecting virus transmission, and basis for virus-vector specificity: determination of endosymbiont involvement in white fly-mediated transmission.

There were no updates in this area.

B.4. Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches.

The whitefly host-free period continues to result in a dramatic decrease in the incidence of TYLCV in the Dominican Republic. Tomatoes planted shortly after the end of the host free period do not get infected until late in the season and produce acceptable yields. Combined with the use of insecticides and TYLCV-tolerant lines later in the season, the processing tomato industry in the Dominican Republic is returning to pre-TYLCV levels of production.

In Costa Rica, living covers (such as coriander and perennial peanuts) and silver plastic mulch were found to reduce the incidence of tomato-infecting geminiviruses in plants where virus pressure was low. These covers were less effective where virus pressure was high. Thus, living covers and/or silver plastic represent a promising management tool, but one that needs to be used in combination with other practices that lead to reduced inoculum pressure.

B. 5. Control of virus diseases; development of virus resistant germplasm through conventional and engineered/molecular approaches. Define prospective strategies for selecting candidate viruses, identifying specific virus diseases to target, and prioritize specific crops and cultivars for protection approaches.

Efforts to screen cotton varieties for resistance to cotton leaf crumple geminivirus (CLCrV) continued. Cotton varieties were screened under field conditions in the Imperial Valley of California for resistance to CLCrV. Resistance was evaluated on the basis of symptom development and detection of viral DNA by a polymerase chain reaction test. A number of potentially resistant lines were detected, in particular line C95-387, which showed no symptoms of infection and in which no viral DNA was detected. Two other lines, C95 483 and C95 383 also showed potential resistance to CLCrV.

In a number of locations efforts are underway to identify tomato germplasm that is resistant to TYLCV and/or well as to develop genetically engineered tomatoes with resistance to TYLCV.

Research approach 6. Pursue specific genetic and biological basis for variability in whitefly biotypes, strains, and species; determine impact of different genotypes/phenotypes on whitefly-mediated transmission and on the epidemiology of virus diseases.

Progress: There were no updates in this area.

**Table B. Viruses, Epidemiology and Virus Vector Interactions.**

| Research Approaches | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Identification and characterization of new or emerging whitefly-transmitted viruses and strains.** | Monitor crops for presence of whitefly-transmitted diseases, and determine relative disease incidence. Begin virus identification and strain differentiation. | | X | Rapid techniques are available for identification and characterization of geminiviruses through sequencing of PCR-amplified viral DNA fragments. This approach was used to show 98% sequence identity between the tomato yellow leaf curl gemini virus (TYLCV) from the Dominican Republic and an Eastern Mediterranean virus strain indicating that the virus was probably introduced on tomato transplants from the Eastern Mediterranean area The use of such sequences in comparisons of viruses are important in establishing their relatedness and origin. Several other assays are available for rapid detection of geminiviruses such as dot blot and squash blot hybridization analysis. |
| **Molecular epidemiology: identification of economic viruses, host plants, and reservoirs, and determination of geographic distribution of viruses.** | Monitor and identify host plants, virus reservoirs in affected areas. Linkages to diagnostic methods for virus ID and tracking. | | X | The use of squash blot analysis using a TYLCV-specific DNA probe to assess the role of weeds as hosts in the Dominican Republic showed that they were not infected with TYLCV and not significant molecular sources for the virus. TYLCV newly discovered in Florida was also 98% identical to the Dominican Republic strain. Geminiviruses, are known throughout the world and distinct viruses are known to occur in many countries. For instance, tomato mottle virus ToMoV) was first detected in Florida in 1989 and is thought to have originated from that state. |

**Table B. Viruses, Epidemiology and Virus Vector Interactions. (Continued)**

| Research Approaches | Year 1 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Virus-vector interactions, factors affecting virus transmission, and basis for virus-vector specificity; determination of endosymbiont involvement in whitefly-mediated transmission.** | Initiate studies on virus-vector interactions and on basis for the specifcity of whitefly-mediated geminivirus transmission. | | X | Studies on feeding duration and position has demonstrated differences in aphids and whiteflies. These differences may determine why some geminiviruses are transmitted by one group and not the other. The use of the autoflourescent GFP gene, in tracking the virus movement and replication in plants indicated that a cell to cell movement of the virus occurred and the virus was not phloem limited. Understanding the movement of the virus in terms of insect feeding behavior may play a role in developing resistant varieties. |
| **Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches.** | Develop approaches to managing cropping systems to reduce vector densities to decrease transmission frequency and inoculum sources, taking into account weed and crop reservoirs in disease incidence and distribution. | | X | Host-free practices used in the Dominican Republic for TYLCV have been successful in reducing the incidence of this disease. In Florida, management of whiteflies with insecticides, field sanitation, and clean transplants has reduced the incidence of ToMoV. In whitefly reduction studies using biological control based IPM, there was a 10% reduction in geminiviruses in squash (See Table D). |

**Table B. Viruses, Epidemiology and Virus Vector Interactions. (Continued)**

| Research Approaches | Year 1 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Control of virus diseases: development of virus resistant germplasm through conventional and engineered/ molecular approaches. Define prospective strategies for selecting candidate viruses, identifying specific virus diseases to target, and prioritize specific crops and cultivars for protection approaches.** | Define strategies for resistance efforts. Identify target viruses. Identify germplasm with virus resistance. Initiate efforts toward defining prospective engineered resistance strategies. Identify candidate crops and recipient cultivars. | | | Resistance to the geminivirus, bean dwarf mosaic virus (BDMV), was found in ?Pinto? bean variety, Othello. Using the GFP gene as a marker, virus infection in this variety was compared with that in a susceptible variety. In the resistant variety, there was a collapse of tissue at the infection site and continuing necrosis in the vascular areas indicating a hypersensitive reaction to the virus. The gene(s) involved in this response may be a source of resistance to this virus either through conventional breeding efforts or by identifying the gene(s) involved. In cotton, some resistance to the cotton leaf crumple virus was reported (See Table F). |
| **Pursue specific genetic and biological basis for variability in whitefly biotypes, strains, and species; determine impact of different genetypes/phenotypes on whitefly-mediated transmission and on the epidemiology of virus diseases.** | Identify differences in species, strains and biotypes with respect to transmission, host range, mating compatabilities, molecular variability, and map the biogeographic distribution of distinct types within the *B. tabaci* species complex. | | | No reports in this area. |

**Table B. Viruses, Epidemiology and Virus Vector Interactions.**

| Research Approaches | Year 2 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Identification and characterization of new or emerging whitefly-transmitted viruses and strains.** | Virus identification and characterization. Develop methods for identifying causal agents and for tracking viruses and strains using molecular methods. | X | | 1. Significant progress has been made in the detection and characterization of tomato yellow leaf curl geminivirus in Florida. A comprehensive survey of the incidence and distribution of TYLCV has been made.<br>2. Evidence has been obtained of a synergistic interaction among three geminivirus DNA components associated with chino del tomate disease of tomato (pepper huasteco geminivirus [PHV] DNA-A and DNA-B and another distinct DNA-A component, chino-A). Here, the disease symptoms induced in three hosts (Nicotiana benthamiana, tomato, and pepper) by PHV plus the chino-A are much more severe than symptoms induced by PHV alone. These results establish that (i) chino del tomate disease may be caused by a complex of geminivirus components, (ii) that complexes of geminivirus components can dramatically influence disease symptom expression and (iii) that identification of geminiviruses based on disease symptoms alone is difficult.<br>3. Tomato geminivirus diseases in Guadeloupe are caused, at least in part, by a strain of potato yellow mosaic geminivirus (PYMV). |

**Table B. Viruses, Epidemiology and Virus Vector Interactions.**

| Research Approaches | Year 2 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Molecular epidemiology: identification of economic viruses, host plants, and reservoirs, and determination of geographic distribution of viruses.** | Continue field studies. Determine economic input of diseases on crop production and associated losses. | X | | 1. The spread of TYLCV in Florida has been extensively documented. The virus has been disseminated throughout the state, including some northern counties. The highest incidences of TYLCV have been correlated with high populations of whiteflies. Extensive host range studies are being conducted with TYLCV in Florida, and TYLCV has been found to infect and cause disease in petunia and common bean. Detection in petunia could have serious implications in terms of exporting this ornamental plant.<br>2. Efforts are being conducted to understand how TYLCV survives in the Dominican Republic during the three-month whitefly host-free period. Using a polymerase chain reaction test to determine the relative contamination of whiteflies with TYLCV, it was found that by the end of the tomato-growing season, TYLCV was readily detected in whiteflies collected from all tomato fields tested. However, within one month of the host-free period, the amount of virus detected in whiteflies collected from plants surrounding tomato fields decreased tremendously. By the end of the host free period, little or no virus could be detected in whiteflies. These results suggest that whiteflies themselves are not likely to be the primary way in which the virus survives during the host-free period. Weeds and other plants in and around fields during the host-free period were then collected and tested for TYLCV using PCR. A number of weeds were found to be symptomless carriers of TYLCV. These results suggest that such symptomless hosts may be the primary way that the virus survives during the host-free period. |

**Table B. Viruses, Epidemiology and Virus Vector Interactions. (Continued)**

| Research Approaches | Year 2 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Virus-vector interactions, factors affecting virus transmission, and basis for virus-vector specificity; determination of endosymbiont involvement in whitefly-mediated transmission.** | Determine specific cellular and molecular factors involved in virus transmission. Study role of endosymbionts in virus acquisition and transmission. | | X | Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches. Continue studies of management approaches for disease abatement. Interdisciplinary studies in conjunction with whitefly control methods in Sections B and C. |
| **Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches.** | Continue studies of management approaches for disease abatement. interdisciplinary studies in conjunction with whitefly control methods in Sections B and C. | X | | In Costa Rica, experiments conducted using living covers (such as coriander and perennial peanuts) and silver plastic mulch demonstrated that these strategies reduced the incidence of geminivirus infection of tomato under moderate whitefly/ geminivirus pressure, but not under high pressure. Thus, living covers and/or silver plastic represent a promising management tool, but one that needs to be used in combination with other practices that lead to reduced inoculum pressure. In the Dominican Republic, the mandatory whitefly host-free period continues to provide an effective management tool for TYLCV. There is a lag period of approximately one-month after planting tomatoes before TYLCV appears and this lag period allows for early-planted tomatoes to provide good yields. This strategy, together with the use of insecticides and tolerant varieties for late season planting, have allowed for the almost complete recovery of the processing tomato industry in the Dominican Republic. |

**Table B. Viruses, Epidemiology and Virus Vector Interactions. (Continued)**

| Research Approaches | Year 2 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Control of virus diseases: development of virus resistant germplasm through conventional and engineered/molecular approaches. Define prospective strategies for selecting candidate viruses, identifying specific virus diseases to target, and prioritize specific crops and cultivars for protection approaches.** | Continue to define suitable strategies for determining target viruses. Isolate and characterize virus-resistant germplasm. Continue work toward engineered resistance in target crops and selected viruses. | X | | 1. Cotton varieties have been screened under field conditions in the Imperial Valley of California for resistance to cotton leaf crumple geminivirus (CLCrV). A number of lines looked promising, particularly C95-387, which showed no symptoms of infection and in which no virus was detected. Two other lines, C95483 & C95383 also showed potential resistance to CLCrV.<br>2. Efforts are underway to identify tomato germplasm that is resistant to TYLCV as well as to develop genetically engineered tomatoes with resistance to TYLCV. |
| **Pursue specific genetic and biological basis for variability in whitefly biotypes, strains, and species; determine impact of different genetypes/phenotypes on whitefly-mediated transmission and on the epidemiology of virus diseases.** | Continue to study differences in species/strains/biotypes with respect to transmission, host range, mating compatibilities, molecular variability. Determine molecular basis of observed variability in biological, molecular & genetic terms. Infer molecular phylogenies from molecular markers. | | X | |

**Reports of Research Progress**
**Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods**
Co-Chairs: Phil Stansly and James Brazzle

**Investigator's Name(s):** D. H. Akey, T. J. Henneberry, & C. C. Chu.

**Affiliation & Location:** USDA, ARS, Western Cotton Research Laboratory, Phoenix, AZ 85040.

**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** June 1993 - October 1998

## Ground Application Techniques That Improved Under-Leaf and Inner Canopy Coverage Cotton: Development and Testing of Hydrostatic Sprayers-Transition from Experimental to Farm Equipment

We increased hydrostatic spray efficiency, by using a gasoline driven single cylinder piston pump that delivered spray pressures > 450 psi on a JD 600 Hi-Cycle. The pump vibrated but a replacement "5-frame" 3 cylinder pump (Cat Pump model 390) ran evenly. It had an output to 12 gpm, a 600-psi rating., but exceeded 700 psi. Studies were conducted at 100 and 400 psi and at 30 and 60 gal/ac. Upper and lower leaf surfaces were tested for coverage at nodes 5, 7, and 9 from top terminal. Coverage was determined by: sprayer application with dyes, a 1% solution of Leucophor EFR Liquid (Sandoz Chemical Corp., Charlotte, NC) and powered sodium fluorescein); ultraviolet color photography of leaf samples 10-12 hr after sampling; and digitalization by video to obtain % coverage, droplet pattern, and size. The piston pumps required priming and was damaged if it run dry. We used the JD 600 Hi-Cycle centrifugal pump to provide a 35 psi prime pressure to the piston pump. The system was shut down immediately if the spray tank emptied or flow ceased. Diaphragm pumps are not prime dependent for structural integrity. We tested a gasoline driven inline medium diaphragm pump (Udor, model Kappa 55) with a 15gal output and 560-psi rating. In 1995-96, a JD 6200 and 6400 tractor (4-WD, high clearance wheels, enclosed cabs and filtered air) were each fitted with: a PTO-driven Kappa 55 diaphragm pump, 47 ft boom (14 rows of 40-in cotton), 8 15-gal spray tanks, 65-gal rinse tank, and for the JD 6400, a 250-gal main tank. Until these units were ready, we used a JD 6000 sprayer with a 3-nozzles/row boom. We tested 40 and 70 psi. in 1995 but with only 15 gal/ac in a large area test. Plots were 5ac and set on a 2-fallow, 6-row plant scheme. The 70 psi applications covered better than 40 psi but were not significantly different in yield nor lint stickiness. High clearance needs were removed by driving through fallow rows. Irrigation water breaking through into one fallow row but not the other was a serious problem. The tractor sank on one side but not the other causing the boom to tilt. One end dipped in cotton, the other raised above it. In 1996, hydraulic rams were installed to tilt-level the booms keeping the left and right sections parallel. In 1997-98, we evaluated distributor-available spray components. We used in-cab control panels to activate application and rinse tanks, boom sections, and pressure. One tractor had radar, and accurate ground speed proved useful. Solenoid valves, rated at 300 psi at 90º F, were used at 250 psi to offset for higher summer temperatures. Brass or bronze spray parts and fittings were replaced with shelf-available plastic parts that worked at 250 psi but needed double-gaskets on drops and daily tightening of plastic swivel bodies. Ground is superior to aerial application for many biorational agents, e.g., the fungi, *Beauveria*. Aerial application is fine for agents with translaminar, vapor, or high toxicity activity. Disadvantages to ground application include: driving time, labor and fuel costs, and chances of weather disruption. Increased scheduling problems may occur with irrigation timing; necessary for dry fields for ground sprayers in solid-plant fields or in soils where water can permeate across beds and berms. Tractors can be used in place of high-clearance spray rigs. We had success with 4-WD tractors equipped with booms that can be leveled and have large vertical adjustment for crop height. Drops that placed small droplets in the canopy reduced drift problems. Drops allowed positioning nozzles between rows to angle spray into canopy under story permitting spraying in windy conditions that would curtail use of broadcast booms because of drift and inefficient spraying. Droplet sizes of 70-150µ formed a mist in the canopy and remained trapped in it until impinging on foliage, in contrast to drifting across and down rows.

Plastic parts reduce cost and are available from spray part distributors. However, the metal and 600 psi-hose component system remained the most reliable and dependable. Some metal components have been used for 8 years; for safety, we change hose components yearly. Our studies show that greater volumes (30 > 15 gal) are the most important parameter in increasing spray efficiencies, followed by pressure increases (250>100-70>40 psi).

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**Dates Covered by the Report:** June - October 1998

## A Sugar Ester (AVA Chemical Ventures, L.L. C.) as a Biorational Agent Against the Silverleaf Whitefly, *Bemisia argentifolii*, in Field Trials in Upland Cotton in Arizona

Deltapine NuCOTN 33$^{B}$ was planted and furrow irrigated in plots 109 ft. in length and 12 rows across (40-in. rows). Plots were separated by 4 fallow rows and 20 ft alleys. A sugar ester (AVA Chemical Ventures, L. L. C.) was used at 0.2 and 0.3%wt/v gal/ac. Applications were made once the silverleaf whitefly reached the action threshold (Univ. AZ recommendations). This treatment was part of a 12-treatment random block design that included a “Best Agricultural Practice regime” (BAP), embedded controls, and a 1-ac block control.

Eggs, small nymphs, and large nymphs were sampled from leaves taken from 5 plants per plot, from the fifth main-stem leaf down from the first expanded terminal leaf. Each sample was counted from a 1-in. disk taken between the main leave stem and the next lateral vein. Adults were sampled from 30 leaves/plot, same location using a binomial decision of counting a leaf as positive if 3 or more adults were present. This indicated a presence of 5 adults on the 5th leaf per plant. Weekly sweeps were taken in all plots for predators, parasites, and *Lygus.* Applications were made by ground with 5 nozzles/row, 1 overhead, and 2 swivel nozzles angled upward on a drop on each side of the row. Sprays were applied at 250 psi and 30 gal./ac.

The 1998 cotton season was a poor production year. The SLWF population reached action threshold (Univ. AZ) between July 27- Aug.6, 1998. Two sprays were applied (8-day period, then the SLWF populations dropped precipitously and did not recover before the end of the cotton season. Sugar esters at 0.2 and 0.3 % wt/v gal/ac had efficacies against immatures as follows: eggs, 42, 43 %; small nymphs, 2, 32 %; and large nymphs, 10, 63 %, respectively. Despite these low efficacy rates for eggs and small nymphs, for the 0.3% rate for the sugar ester, the SLWF populations remained below action thresholds. Only egg efficacies were statistically significant by ANOVA and LSD ($P < 0.05$). Buprofezin (Applaud™ 70 WP, AgrEvo, 0.35 lb. AI/ac) was the first BAP treatment was to be applied. Because of the unusual nature of the SLWF population decline, no other BAP treatments were made. Buprofezin was used as a standard and had egg, small nymph, and large nymph efficacies of 28, 37, 38 %, respectively. Comparatively, 0.3% sugar ester was as effective at controlling SLWF, especially against reducing numbers of large nymphs. The sugar ester at 0.3% was effective at controlling silverleaf whitefly immature life stages.

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**Dates Covered by the Report:** June - October 1998

## Azadirachtin (as Bollwhip®), a Biorational Agent Against the Silverleaf Whitefly, *Bemisia argentifolii*, in Field Trials in Upland Cotton in Arizona

Deltapine NuCOTN $33^{B}$ was planted and furrow irrigated in plots 109 ft. in length and 12 rows across (40-in. rows). Plots were separated by 4 fallow rows and 20 ft alleys. Bollwhip™ (Thermo Trilogy) was used in a 4.5% formulation at 6 oz product /ac. The treatment was part of a 12-treatment random block design that included a "Best Agricultural Practice regime" (BAP), embedded controls, and a 1-ac block control.

Eggs, small nymphs, and large nymphs were sampled from leaves taken from 5 plants per plot, from the fifth main-stem leaf down from the first expanded terminal leaf. Each sample was counted from a 1-in. disk taken between the main leave stem and the next lateral vein. Adults were sampled from 30 leaves/plot, same location using a binomial decision of counting a leaf as positive if 3 or more adults were present. This indicated a presence of 5 adults on the 5th leaf per plant. Weekly sweeps were taken in all plots for predators, parasites, and *Lygus.* Applications were made by ground with 5 nozzles/row, 1 overhead, and 2 swivel nozzles angled upward on a drop on each side of the row. Sprays were applied at 250 psi and 30 gal./ac.

The 1998 cotton season was a poor production year. The SLWF population reached action threshold (Univ. AZ recommendations) between July 27- Aug.6, 1998. Two sprays were applied (8-day period, then the SLWF populations dropped precipitously and did not recover before the end of the cotton season. Azadirachtin as Bollwhip®) had efficacies against immatures as follows: eggs, 32 %; small nymphs, 35 %; and large nymphs, 77%, respectively. Despite these low efficacy rates for eggs and small nymphs, the SLWF populations remained below action thresholds. Only egg efficacies were statistically significant by ANOVA and LSD ($P < 0.05$). Buprofezin (Applaud™ 70 WP, AgrEvo, 0.35 lb. AI/ac) was the first BAP treatment was to be applied. Because of the unusual nature of the SLWF population decline, no other BAP treatments were made. Buprofezin was used as a standard and had egg, small nymphs, and large nymph efficacies of 28, 37, 38 %, respectively. Comparatively, Bollwhip® was as effective at controlling SLWF, especially against reducing numbers of large nymphs.

**Investigator's Name(s):** D. H. Akey & C. C. Chu.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** June - October 1998

## Acetamiprid as NI 25 Against the Silverleaf Whitefly, *Bemisia argentifolii*, in Field Trials in Upland Cotton in Arizona

Deltapine NuCOTN 33[B] was planted and furrow irrigated in plots 109 ft. in length and 12 rows across (40-in. rows). Plots were separated by 4 fallow rows and 20 ft. alleys. Acetamiprid (Rhone-Poulenc, NI-25) was applied at 3 rates of 24.3 g, 36.45 g, and 48.6 g AI/ac. Applications were made once the silverleaf whitefly reached the action threshold (Univ. AZ recommendations). This treatment was part of a 12-treatment random block design that included a "best agricultural practice regime," and a 1-ac block control.

Eggs, small nymphs, and large nymphs were sampled from leaves taken from five plants per plot, from the fifth main-stem leaf down from the first expanded terminal leaf. Each sample was counted from a 1-in. disk taken between the main leave stem and the next lateral vein. Adults were sampled from 30 leaves/plot, same location using a binomial decision of counting a leaf as positive if three or more adults were present. Weekly sweeps were taken in all plots for predators, parasites, and *Lygus.* Applications were made by ground with 0.5 nozzles/row; 1 overhead, and 2 swivel nozzles angled upward on a drop on each side of the row. Sprays were applied at 250 psi and 30 gal./ac. The 1998 cotton season was a poor production year. The SLWF population reached action thresholds between July 27- August 6, 1998.

Only one spray was applied of each rate, then the SLWF populations dropped precipitously and did not recover before the end of the cotton season. However, acetamiprid was effective at controlling silverleaf whitefly.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management and Application Methods.

**Dates Covered by the Report:** 1998

## *In vitro* Acetylcholinesterase Inhibition in *Bemisia tabaci* and its Relevance to Organophosphorus Resistance Expressed in Bioassays

The target site for organophosphorus (OP) insecticides is the nerve enzyme, acetylcholinesterase (AChE). The efficacy of OPs at this target site is primarily governed by their affinity for the active site on the enzyme. In *Bemisia tabaci*, as in many pest species, modifications to the AChE can confer considerable levels of resistance.

All OP resistant *B. tabaci* populations express AChE insensitivity as the predominant resistance mechanism. In populations expressing the same insensitive variant, differences in OP resistance levels are likely to be caused by additional mechanisms. However, there is no evidence that these can confer any significant resistance in the absence of target-site insensitivity. Thus, the insensitive AChE will confer a baseline level of resistance. In *B. tabaci*, a clear correlation exists between the levels of insensitivity measured using *in vitro* biochemical assays and levels of resistance expressed in toxicological bioassays. However, insensitivity factors can be at least an order of magnitude greater than the resistance factors determined from bioassays. A detailed kinetic analysis of the AChEs in resistant *B. tabaci* shows that, in addition to the importance of intrinsic insensitivity, differences in affinity for the substrate (acetylcholine, ACh) and the turnover of ACh are extremely important

Despite the knowledge we have on resistance to OPs in *B. tabaci*, these chemicals are still widely used in management programs designed to control this pest. Furthermore, OPs (and carbamates, which also target AChE) are used in the management of other insects in the pest complex and these treatments could have inadvertent effects on the resistance status of whiteflies through the selection of mechanisms additional to AChE insensitivity, particularly if they confer cross resistance to other insecticide classes.

In California, one form of insensitive AChE has been identified in field populations of *B. tabaci*. The purpose of this study was to determine the relative potencies of OPs against this enzyme, concentrating on those chemicals which *B. tabaci* is likely to come into contact with in California agriculture systems. By determining the *in vitro* effects of OPs at the level of the target-site, it will be possible to identify the most effective compounds for use in field treatments, as well as those which represent a high resistance risk.

**Investigator's Name(s):** Luko Hilje, Douglas Cubillo, & Guido Sanabria.

**Affiliation & Location:** Plant Protection Unit, CATIE. Turrialba, Costa Rica.

**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** August 1996 - December 1998

## Bitterwood (*Quassia amara*) Extracts Kill *Bemisia tabaci* Adults

*Bemisia tabaci* (Gennadius) is an important pest of several food crops in Mesoamerica and the Caribbean, especially as a geminivirus vector in beans, tomato, and bell pepper. Grower response to its damage has been the overuse of insecticides, sometimes with daily applications, which has increased the risk of insecticide residues on vegetables, water and soil contamination, toxicity to field workers, and substantial reductions in grower's income; in addition, this overuse has fostered the appearance of *B. tabaci* insecticide-resistant strains, as well as the decline of natural enemy populations of *B. tabaci* and other crop pests. The importance of these problems justifies the development of insecticides with new modes of action, among which some active principles present in plants offer a good potential, as it currently happens with neem (*Azadirachta indica*, Meliaceae), seed extracts.

There is a sound possibility with bitterwood, *Quassia amara* L. ex Blom (Simaroubaceae), which early in the century was one of the classical botanical insecticides, as its wood contains several quassinoids, such as quassin and neoquassin, which are toxic to several homopteran, lepidopteran and coleopteran species. Currently, there is a growing interest in promoting the utilization of this wild shrub as an economic resource for Indian communities in Mesoamerica, so that several of its ecological, silvicultural, and marketing aspects have been investigated in recent years.

In order to test the insecticidal properties of bitterwood against *B. tabaci*, a greenhouse experiment was set up at CATIE, in Turrialba, Costa Rica. Two bitterwood extracts (aqueous and metanolic) were tested, each one in the following six doses: 5, 10, 15, 20, 25 and 50 ml/l of water (Q05, Q10, Q15, Q20, Q25 y Q50). They were compared to a relative (endosulfan, Thiodan 35% CE, at 0.875 g a.i./ l water) and an absolute control (distilled water). The source solution of bitterwood was prepared from 1.3 kg of wood, as to obtain a final volume of 250 ml. A completely randomized block design was used. The substances were sprayed over bean plants (cv. Negro huasteco), which were placed inside sleeve cages, to which 100 whitefly adults per replicate were released. The number of landed (2, 4 y 24 h later) and living adults (48 h later), as well as deposited eggs were counted.

All the doses of both bitterwood extracts were able to kill whitefly adults. However, the metanolic extracts in general were superior, especially at higher doses (Q20, Q25 and Q50). The highest dose (Q50) did not differ from endosulfan (p# 0.05), which was the best treatment in terms of reducing landing adult numbers, living adults after 48, and oviposition, excepting that endosulfan killing effect was attained fastest.

Bitterwood extracts seem not to pose risks to people, as they are commonly used as a natural medicine for digestive problems. Nevertheless, their persistence could become a limiting factor for using them on vegetables, because of their very bitter taste to people.

**Investigator's Name(s):** Rosalind R. James & Gary Elzen.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** June - December 1999

## Integrating the Biocontrol Agent *Beauveria bassiana* with Imidacloprid

Imidacloprid is a chloronicotinyl analogue of nitromethylene insecticidal compounds, and has been used effectively to control whiteflies in melons and cucumbers. It is applied either as a soil drench (often at the time of planting) or as a foliar spray. *Beauveria bassiana* is an entomopathogenic fungus, also effective in curcurbits. This biopesticide is applied as a foliar spray using high pressure (400 psi) with drop nozzles directed at the undersides of leaves. *B. bassiana* usually infects only nymphs.

Combining *B. bassiana* with imidacloprid has several potential benefits. When imidacloprid is applied as a soil drench at the time of planting, its effectiveness declines during the season, and spray applications of *B. bassiana* could be used to control *Bemisia* populations that develop later in the season. Alternatively, *B. bassiana* and imidacloprid could be applied foliarly together as a tank mix to control nymphs. Applying insecticide after planting allows the grower to wait and see if whitefly populations are going to reach significant levels before money has been spent on treatments. Strategies for combining the biological and chemical pesticides could also be used to manage against the development of whitefly populations that are resistant to imidacloprid. Combining the two pesticides would be most effective if they were synergistic, each enhancing the activity of the other.

We tested for synergy in the laboratory using 21-d old, potted, melon plants. We tested two methods of application. In the first, the two pesticides were sprayed onto plants infested with 3rd instar *B. tabaci* (B- biotype). Application rates included 1x and 0.5x the field rates, and the pesticides were applied both alone and in tank mixes. In the second experiment, potted plants were soil-drenched with imidacloprid four days prior to being infested with whiteflies. *B. bassiana* was applied as a foliar spray when the nymphs in the controls reached the 3rd instar. Again, we used full and half field rates, and the treatments were applied alone and in combination in a 2-way analysis of variance design.

Imidacloprid showed no effect on the germination rate or colony formation of *B. bassiana* on nutrient agar. However, when imidacloprid and *B. bassiana* were combined for whitefly control, an inhibitory effect was seen. That is, imidacloprid was more effective alone than in combination with *B. bassiana*. This interactive effect was highly significant ($P \leq 0.0003$ for foliar applications of both pesticides; $P \leq 0.0001$ for the experiment using the soil drench of imidacloprid).

For example, both pesticides caused a significant decline in the number of insects per leaf. A single application of *B. bassiana* at field rate caused an 81% decline in whitefly densities, and the imidacloprid drench at field rate caused a 100% decline. When full field rates of each were combined, the population declined 97%. Using the same rate of imidacloprid, but reducing *B. bassiana* to half rate resulted in greater control, with a 99.3% decline in whitefly densities. Although combining *B. bassiana* and imidacloprid may give sufficient control, imidacloprid works more effectively alone. Combining these two pest control methods will probably not benefit producers. A reasonable explanation for how *B. bassiana* can inhibit imidacloprid is being sought.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** 1998

## Management of *Bemisia argentifolii* with Application of Biorational Insecticides and Imidacloprid on Cantaloupe in Spring in South Texas

The silverleaf whitefly, *Bemisia argentifolii*, is still the one of most important pests on melons in south Texas. The objective of this study was to develop a season-long whitefly management program for spring cantaloupe with application of insect pathogens and insect growth regulators (IGRs) in the early spring season, and application of imidacloprid (Admire) in the early mid-season to control the whitefly for the remaining season. The materials used included Mycotrol WS (B. bassiana, Mycotech) at 1 lb/ac, Naturalis-L (B. bassiana, Troy Biosciences) at 1 lb/ac; Knack (pyriproxyfen) at 1 lb/ac; Applaud (buprofezin) at 0.35 lb/ac; untreated plots as control. Admire 2F (Imidacloprid, Bayer) was side-injected 56 g [AI]/ac). Cantaloupe seedlings were transplanted in the field on January 22. The plots were arranged in a randomized complete block design with 4 replications. Mycotrol and Naturalis-L were sprayed weekly starting from March 4 to May 11 for 11 weekly applications, and Knack and Applaud, biweekly for 5 applications. Admire was either dripped through the irrigation system at transplanting or side-injected 15 cm deep in the soil on April 14 in the mid-season.

Adult population was high during the entire season. Numbers of adults among the treatments were significantly different during the 12 sampling dates except for the first week that there was no significant difference among the treatments. The treatments with Admire at transplanting had the lowest whitefly population before the mid-season. The treatment of Admire applied twice had the lowest adult population. In the treatments of Admire applied in the mid-season, number of adults was high in the early season. After the mid-season, adult population was still above the economic threshold even the overall population was significantly lower than other treatments. Mycotrol, Naturalis-L, Knack and Applaud, when used alone, did reduce the adult population in the early season, but did not provide satisfactory control, and also there were no significant differences among them. After the mid-season, when Admire was applied, numbers of adults on the treated plants significantly reduced even the population was still greater than the economic threshold, indicating that the application of Admire might be too late. The number of nymphs and pupae was significantly different among the treatments over all sampling dates. Ten weekly applications of Mycotrol and Naturalis-L alone did reduced the whitefly population but did not reduce the whitefly immature population below the economic threshold. Although the whitefly population on the plants treated with Knack and Applaud alone was significantly lower than on untreated plants after 5 biweekly applications, they did not provide effective control of the nymphs either. Multiple applications of the 4 biorational insecticides, Mycotrol, Naturalis-L, Knack and Applaud in the early season followed by a mid-season application of imidacloprid, did significantly reduced the population of live whitefly nymphs and pupae on the plants, even in some treatments the number of nymphs and pupae was still above the economic threshold. All biorational insecticides tested in this experiment did not provide good control, especially in the late season that most plants treated with biorational insecticides were collapsed and died prematurely except for the plants treated with imidacloprid because whitefly population in the experimental field was much greater than other fields on the same farm during the entire season. However, Admire still was the most effective insecticide tested in this study, even its effectiveness lasts a maximum of 11 wk. Admire applied once at transplanting was effective against the whitefly before the mid-season, but did not give adequate whitefly control after the mid-season. Admire applied twice, at transplanting and in the mid-season, provided the best control of both whitefly adults and immatures even in some treatments whiteflies were slightly greater than the economic threshold. This could be explained that the healthy green plants attracted more adults from the nearby died or dying plants, or adults on these died and dying plants were forced to relocate their feeding sites to the greener and healthier plants.

**Investigator's Name(s):** Eric T. Natwick & Keith S. Mayberry.

**Affiliation & Location:** UC Cooperative Extension, UC Desert Research and Extension Center, Holtville, CA.

**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** September 1997 - January 1998

## Evaluation of Selected Insecticides for Silverleaf Whitefly Control in Cabbage

Cabbage var. Primero was sown at UC Desert Research & Extension Center 16 September 1997. Six insecticide treatments and an untreated control were replicated four times in a randomized complete design experiment. Insecticide treatments were as follows: Admire 2F at 0.5 lb ai/acre injected 3 inches below the seed-line pre-plant, Capture 2 EC at 0.08 lb ai/acre plus Thiodan 3 EC 0.75 lb ai/acre, CGA215944 50 WP at 0.062 lb ai/acre, CGA215944 50 WP at 0.094 lb ai/acre, CGA215944 50 WP at 0.062 lb ai/acre plus Sylgard 309 at 4 fl oz/100 gal, and CGA215944 50 WP at 0.094 lb ai/acre plus Sylgard 309 at 4 fl oz/100 gal,. Foliar sprays were applied on 9, 15, 22 & 29 October, and 5 & 12 November, 1997. Silverleaf whitefly, *Bemisia argentifolii*, were sampled by counting adults via leaf turn and eggs and nymphs were counted on 2.54 $cm^2$ of leaf surface from basal leaves on ten plants at random from each plot on, 1, 13, 21 & 27 October and 4, 11, 17 & 24 November, and 2 & 8 December, 1997. Mature marketable lettuce heads per 0.002 acres per plot were harvested and weighs were recorded in pounds.

The of adult silverleaf whitefly means for the untreated control were greater than insecticide treatments on sampling dates after October 13 and for the seasonal mean values, p # 0.05. The nymphal means for the Capture + Thiodan treatment were lower than the untreated control on all post-treatment sampling dates and for the seasonal mean. The nymphal means for the Admire treatment were lower than the untreated control on all post-treatment sampling dates, except 13 October, and for the seasonal mean. The nymphal means for the CGA215944 treatments were rarely different than the untreated control throughout the study. There were no differences among the treatments for numbers of cabbage heads or weight of cabbage heads.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** March - June 1998

## Silverleaf Whitefly Control In Spring Planted Cantaloupe Melons, 1998

A stand of Cantaloupe melons, var. Topmark, was established at UC Desert Research & Extension Center 19 March 1998. Seven insecticide treatments and an untreated control were replicated four times in a randomized complete design experiment. Insecticide treatments were as follows: CGA-293343 2 SC as a soil injection at 0.036 lb ai/acre followed by CGA-215944 50 WG as a foliar spray at 0.089 lb ai/acre, CGA-293343 2 SC as a soil injection at 0.043 lb ai/acre followed by CGA-293343 25 WG as a foliar spray at 0.089 lb ai/acre, Admire 2F as a soil injection at 0.25 lb ai/acre followed by Applaud 70 WP as a foliar spray at 0.25 lb ai/acre, Admire 2F as a soil injection at 0.25 lb ai/acre followed by Applaud 70 WP as a foliar spray at 0.037 lb ai/acre, Admire 2F as a soil injection at 0.25 lb ai/acre followed by Applaud 70 WP at 0.25 lb ai/acre plus Phaser 3 EC at 0.75 lb ai/acre as a foliar spray, Admire 2F as a soil injection at 0.25 lb ai/acre followed by Capture 2 EC at 0.08 lb ai/acre plus Thiodan 3 EC at 0.75 lb ai/acre as a foliar spray, and Admire 2F as a soil injection at 0.25 lb ai/acre. Foliar insecticide treatments were applied four times at one week intervals from 18 & 26 May, 2 & 16 June, 1998 with the exceptions of CGA-293343 25 WG as a foliar spray at 0.089 lb ai/acre and CGA-293343 25 WG as a foliar spray at 0.089 lb ai/acre which were only applied on 16 June. Silverleaf whitefly adults were counted on the fifth leaf from the terminal of the main stem cane from ten plants at random in each plot via the leaf turn method on 1, 3, 11, 15, 25 May, 1, 8, 24 and 30 June 1998. Silverleaf whitefly eggs and nymphs were counted on 2.54 cm leaf disks from ten crown leaves extracted from randomly selected melon plants in each plot on 4, 11, 18, 25 May, 1, 8, 24, and 30 June 1998.

There were no differences among treatments for adult counts on sampling dates from 1 May through 1 June. The non-treated control and the CGA-215944 treatments had more adults than Admire 2F followed by Applaud 70 WP + Phaser 3 EC and Admire 2F followed by Capture 2 EC + Thiodan 3 EC on 8 June (p# 0.05). The Admire 2F followed by Applaud 70 WP treatments had fewer whitefly adults than the control and CGA-293343 2SC followed by CGA-293343 25 WG. On 16 June, Admire 2F followed by Capture 2 EC + Thiodan 3 EC had fewer whitefly adults than all other treatments except Admire 2F as a soil injection at 0.025 lb ai/acre followed by Applaud 70 WP as a foliar spray at 0.037 lb ai/acre which had fewer adults than the control, the CGA-215944 treatments and Admire used alone. On 24 June, the control had more adults than all other treatments and Admire 2F followed by Capture 2 EC + Thiodan 3 EC had fewer whitefly adults than all other treatments except CGA-293343 2 SC as a soil injection at 0.043 lb ai/acre followed by CGA-293343 25 WG as a foliar spray at 0.089 lb ai/acre and Admire 2F as a soil injection at 0.25 lb ai/acre followed by Applaud 70 WP as a foliar spray at 0.25 lb ai/acre. On June 30, CGA-293343 2 SC as a soil injection at 0.036 lb ai/acre followed by CGA-215944 50 WG as a foliar spray at 0.089 lb ai/acre had fewer whitefly adults than all other treatments except the control, Admire alone and CGA-293343 2 SC as a soil injection at 0.043 lb ai/acre followed by CGA-293343 25 WG as a foliar spray at 0.089 lb ai/acre.

The control had more whitefly nymphs that the Admire treatments on 11 May through 25 May. The nymphal means for the CGA-215944 2 SC treatments were not different from the control until after the addition of foliar sprays on 16 June. Admire followed by Applaud at 0.37 lb ai/acre, Applaud plus Phaser or Capture Plus Thiodan provided the best control of whitefly nymphs through the season.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** March - December 1998

## Silverleaf Whitefly Control In Cotton, 1997

A stand of cotton, var. DPL 5415, was established at UC Desert Research & Extension Center 25 March 1998. Fourteen insecticide treatments and an untreated control were replicated four times in a randomized complete design. Insecticide treatments were as follows: Applaud 70 WP at 0.35 lb ai/a applied 7 and 21 July followed by Danitol 2.4 EC at 0.2 lb al/a plus Orthene 90S at 0.5 lb ai/a applied 4 August, Applaud 70 WP at 0.35 lb ai/a plus Phaser 3EC at 0.75 lb ai/a applied 7 and 21 July followed by Danitol 2.4 EC at 0.2 lb al/a plus Orthene 90S at 0.5 lb ai/a applied 4 August, Applaud 70 WP at 0.35 lb ai/a plus Decis 02. EC at 0.02 lb ai/a applied 7 and 21 July followed by Danitol 2.4 EC at 0.2 lb al/a plus Orthene 90S at 0.5 lb ai/a applied 4 August, Ovasyn 1.5 EC at 0.25 lb ai/a plus Phaser 3 EC at 0.75 lb ai/a applied 7, 14, 21, 28 July and 4 August, Knack 0.86 EC at 0.05 lb ai/a applied 7 July followed by Ovasyn 1.5 EC at 0.25 lb ai/a plus Phaser 3 EC at 0.75 lb ai/a applied 21, 28 July and 4 August, Danitol 2.4 EC at 0.2 lb al/a plus Orthene 90S at 0.5 lb ai/a, EXP61486A 70 WP (acetamiprid) at 0.022 lb ai/a, EXP61486A 70 WP at 0.044 lb ai/a, EXP61486A 70 WP at 0.075 lb ai/a, EXP61486A 70 WP at 0.1 lb ai/a, TADS12222 1.67 EC (acetamiprid + fipronil) at 0.044 lb ai/a, TADS12222 1.67 EC (acetamiprid + fipronil) at 0.088 lb ai/a, and AVA CHEM. Sugar ester at 0.3% AI w/v in water. All insecticide treatments were applied 7, 21, 28 July and 4 August unless otherwise designated. Helena Buffer PS at 23.6 ml/5 gal. and Sylgard 309 at 5.9 ml/5 gal. were used with all insecticide spray treatments. Silverleaf whitefly adults were sampled from ten plants at random in each plot via the leaf turn method using the fifth main stem leaf from the terminal on 10, 22, 29 June, 6, 13, 20, 27 July, 3, 11 August 1998. Silverleaf whitefly eggs and nymphs were counted on 1.54 $cm^2$ leaf disks from 5th position, main-stem terminal leaves extracted from ten randomly selected plants in each plot on the same dates adult whiteflies were sampled. Seed cotton was hand picked from 0.002 acre per plot and yield data were recorded on 28 August 1998. Seed cotton samples were ginned at the USDA-ARS Western Cotton Research Laboratory in Phoenix, AZ and lint samples were sent to the USDA/ARS Cotton Quality Research Station in Clemson, SC for stickiness and sugar analysis.

The nymphal means for the sugar ester treatment was not different than the untreated control on any of the sampling dates. The EXP61486A, TADS1222, and Danitol + Orthene treatments provided the highest levels of control for silverleaf whitefly adults and nymphs with means lower than the untreated control on all post-treatment sampling dates for both adults and nymphs, p # 0.05. There were no differences among treatments for seed cotton yields.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** September 1997 - January 1998

## Evaluation of Selected Insecticides for Silverleaf Whitefly Control in Iceberg Lettuce

Iceberg lettuce var. Desert Queen was sown at UC Desert Research & Extension Center 16 September 1997. Four insecticide treatments and an untreated control were replicated six times in a randomized complete design experiment. Insecticide treatments were as follows: Admire 2F at 0.25 lb ai/acre injected 3 inches below the seed-line pre-plant, Applaud 70 WP at 0.25 lb ai/acre, Applaud 70 WP at 0.38 lb ai/acre, Applaud 70 WP at 0.38 lb ai/acre plus Phaser 3 EC at 0.75 lb ai/acre. Foliar sprays were applied on 9, 15, 22 & 29 October, and 5 November, 1997. Silverleaf whitefly, *Bemisia argentifolii*, were sampled by counting adults via leaf turn on ten plants at random from each plot on, 1, 14, 20 & 28 October and 3 & 11 November, 1997. Silverleaf whitefly eggs and nymphs were counted on 2.54 $cm^2$ of leaf surface from basal leaves of ten plants at random from each plot on 1, 14, 20, & 28 October, and 3 November, 1997. Mature marketable lettuce heads per 0.002 acres per plot were harvested and weighs were recorded in pounds.

The seasonal mean values of adult silverleaf whitefly for the untreated control were greater than all insecticide treatments except Applaud 70 WP at 0.25 lb ai/acre, p # 0.05. The seasonal mean of silverleaf whitefly nymphs for the untreated control was greater than all of the insecticide treatments on 28 October. There were no differences among treatments for seasonal means of silverleaf whitefly nymphs. There were no differences among the treatments for numbers of lettuce heads or weight of lettuce heads.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** September 1997 - February 1998

## Field Evaluation of the Particle Films M-96-018 and M-97-009 for Whitefly Control on Bell Peppers and Collards

Trials were conducted in Weslaco, TX, to evaluate two particle films for control of *Bemisia argentifolii* on bell peppers, *Capsicum annuum* L. 'Capistrano', and collards, *Brassica oleracea acephala* DC. Individual plots consisted of six rows of bell peppers or collards arranged in single-row (peppers) or double-row (collards) beds, at 40-inch spacing, 60-ft in length with a 10-ft buffer between plots. Three replicated plots for each of two treatments and two controls were included in a randomized complete block design. The treatments were M-96-018 Hydrophobic Particle Film and M-97-009 Hydrophilic Particle Film. M-96-018 (25 pounds/acre) was stirred in 98% methanol and M-97-009 (25 pounds/acre) in the spray adjuvants Pinene II (peppers trial) or M03 (collards trial), prior to mixing with water (4 gallons of methanol or 14 ounces of Pinene II or 1 pint of M03 per 100 gallons of water). An untreated control and an adjuvant control were included in each trial. Applications were made using a high pressure hydraulic sprayer with three (peppers) or four (collards) drop nozzles (Lilac Albuz) per bed, at 200 (peppers) or 400 (collards) psi pressure and 100 gpa application volume. Treatments in the peppers trial were applied on 10 and 17 September; and 1, 7, and 15 October. Treatments in the collards trial were applied on 9, 16, 23, and 30 December, and 6, 20, and 27 January. Weekly evaluations (1 day before spray applications and again one week after the last spray application) were made by counting live whitefly immatures (unhatched eggs + nymphs + pupal cases) in one circular area (2 $cm^2$) of leaf surface on 10 plants/plot. Differences among treatments were separated using analysis of variance (ANOVA) on log $(n + 1)$ transformation of the population data. Bell peppers were harvested on 3 and 10 December from one full, 13. 1-feet long section in the four middle beds of each plot. Collards were harvested on 10 February from one full, 10-feet long row section in the four middle beds of each plot. Weight (peppers) and bundles (collards; one bundle is made from one large up to three small plants per bundle, damaged and soiled leaves removed) values were transformed to corresponding log values before ANOVA. Back-transformed data are presented.

Pre-treatment populations of whitefly immatures on bell peppers were high (overall mean 137.3 immatures per 2 $cm^2$ of leaf surface). There were no significant differences in numbers of whitefly immatures among treatments and controls in the pretreatment ($P = 0.925$) and subsequent counts (all $P > 0.05$). Populations gradually at a similar rate in all treatments and controls to a low overall mean of <1 immature per 2 $cm^2$ on 22 October. Although there were no significant differences in yields among the two treatments and two controls ($P = 0.295$), the plots treated with M-96-018 and M-97-009 yielded an average of 1,666 and 1, 125 more pounds of marketable bell peppers per acre than the untreated control plots (6,542 pounds per acre), respectively.

Whitefly pressure was low in the collards trial (overall mean 2.4 immatures per 2 $cm^2$ of leaf surface in the pre-treatment counts). There were no significant differences in populations of whitefly immatures among treatments and controls in the pre-treatment ($P = 0.324$) and subsequent counts (all $P > 0.05$). Whitefly populations remained low in all treatment and control plots during the entire season. No significant differences in yields were found among the two treatments and two controls. However, the plots treated with M-97-009 yielded 1,531 more bundles of marketable greens per acre than the untreated control plots (13,338 bundles per acre).

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** Spring 1998

## Field Evaluation of Mycotrol® (Conidia of *Beauveria bassiana* Strain GHA), Blastospores of *Paecilomyces fumosoroseus* Strain 612, the Particle Film M97-009, and One Sugar Ester for Control of Whiteflies on Melons

Individual plots, at Weslaco, TX, consisted of 4 beds of cantaloupe melon *(Cucumis melo* L.) 'Perlita' planted on 5 March in 80-inch single-row beds, 45-ft in length with a 8-ft buffer between plots. Three replicated plots for each of 9 treatments and 1 untreated check were included in a completely randomized experimental design. The plots received one of the following treatments: Mycotrol 22WP @ $1x10^{13}$ conidia/acre + the adjuvant Silwet® L77 (0.04%); Mycotrol 22WP @ $1x10^{13}$ conidia/acre; M97-009 @ 25 lbs/acre + the adjuvant M03 (0.125%); Mycotrol ES9505 @ $1x10^{13}$ conidia/acre; air-dried blastospores of *Paecilomyces fumosoroseaus* formulated in diatomite @ $1x10^{13}$ blastospores/acre + the adjuvant Silwet L77 (0.04%) [the rate was $5x10^{12}$ blastospores/acre on 6 May]; tank mix of Mycotrol ES @ $1x10^{13}$ conidia/acre + M97-009 @ 25 lbs/acre + the adjuvant M03; one sugar ester (technical) @ aqueous 0.3% solution/acre; Mycotrol ES @ $1x10^{13}$ conidia/acre; Mycotrol ES @ $1x10^{13}$ conidia/acre + the adjuvant Silwet® 560 (5% v/v of Mycotrol ES); or untreated check. Applications of Mycotrol and Mycotrol\M97-009 were made using a high pressure hydraulic sprayer with 3 (first 2 sprays), 5 (next 3 sprays) or 7 (last spray) drop nozzles (Lilac Albuz) per bed, at 400 psi pressure and 14 (3 nozzles), 22.5 (5 nozzles) or 31.5 (7 nozzles) gpa application volume. These treatments were applied on 15, 22 and 29 April; and 6, 13 and 21 May. M97-009 was applied on the above dates, using the above sprayer, number of nozzles per bed and pressure, but at 100 gpa application volume. The sugar ester treatment was applied only on 15 (3 nozzles) and 29 (5 nozzles) April and 13 (5 nozzles) May using the above sprayer, pressure and application volumes. Blastospores were applied on the same dates as the Mycotrol treatments, but using a motorized knapsack mistblower (Solo Master 412) delivering 45 gpa; both sides of each bed were sprayed. Evaluations were made by counting living *Bemisia argentifolii* nymphs (all 4 instars plus pupae)/unit area (2 $cm^2$ leaf area) on 10 plants in the center of each plot on 14 (precount), 21, and 28 April, and 5, 12, 19 May and 26 May. Differences among treatments were separated using one-way ANOVA on log $(n + 1)$ transformation of the population data and the Tukey HSD test. Untransformed means are presented. Abbott's percent efficacy was calculated for each treatment.

Whitefly pressure was moderate in this trial. There were significant differences in living whitefly nymphs among treatments and control in the precounts taken on 14 April ($P = 0.008$). The Mycotrol ES/Silwet 560 treatment had significantly more nymphs than did all other treatments and untreated check; the Mycotrol 22WP treatment and the untreated check had significantly fewer nymphs than did all other treatments. Immature whitefly populations increased in all of the plots during the first week of the trial. There were significant differences among treatments on the last day of sampling, 26 May ($P < 0.001$). The seasonal treatment effects on immature whiteflies were examined through analysis of the integrated population curves for this life stage. The differences in the areas under the treatment curves (not shown) best represent whitefly pressure. Based on seasonal means, there were clear treatment differences in living immature whiteflies ($P < 0.001$). The seasonal densities of whitefly nymphs (Tukey test) [and respective seasonal Abbott's percent efficacies of treatments in reducing nymphal populations] were: Mycotrol 22WP/Silwet L77 - 37.0 (bc) [39.4%]; Mycotrol 22WP - 37.5 (ab) [38.4%]; M97-009/MO3 - 34.5 (ab) [43.5%]; Mycotrol ES9505 - 35.8 (b) [41.4%]; *P. fumosoroseus* blastospores/Silwet L77 - 19.7 [67.7%]; Mycotrol ES/M97-009/MO3 - 46 (ab) [23.7%]; sugar ester - 32.1 (b) [47.6]; Mycotrol ES - 27.9 (bc) [54.3%]; Mycotrol ES/Silwet 560 - 41.5 (ab) [32. 1%]; and untreated check - 61.1 (a). Of all the treatments applied to melons against immature whiteflies, *P. fumosoroseus* blastospores proved to be significantly more effective than parallel treatments and much more effective than no treatment.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** Fall and Winter 1998

## In *Vitro* and In *Vivo* Compatibility of Selected Fungicides with Fungal Pathogens of *Bemisia* Whiteflies

Formulated fungicides tested were chlorothalonil [Bravo 6.0 flowable (F)], propionazole [Tilt 4.17 F], azoxystrobin [Quadris 2.08 F], and sulfur-tribasic copper sulfate [Top Cop 6.25-1.0 F]. Rates [kg (AI)/ha] were: chlorothalonil 1.67, propionazole 0.14, azoxystrobin 0.09, and sulfur-tribasic copper sulfate 3.47.

**In *Vitro* Bioassay**. Fungicides were mixed in Sabouraud dextrose agar to equivalent field rates. One fungal plug (1 cm diam.) consisting of mycelia only was transferred to the center of a Petri dish (10 dishes per treatment and control). Dishes were incubated at 25ºC and 16:8 (L:D) h. The dishes of each treatment and control were incubated in isolation because volatile products or by-products could influence fungal growth on other treatment or control dishes. Radial growth was measured daily for 7 d. The 7-d cumulative growth data were analyzed by one-way ANOVA. After the 7-d incubation period, *B. bassiana* radial growth was 38.5 mm in the controls and 3.5, 4.4, and 11. 3 mm on the Bravo, Quadris, and Top Cop treated agar, respectively. No growth occurred on the Tilt-treated agar plates. Treatment effects were significantly different ($P < 0.001$). *P. fumosoroseus* radial growth at day 7 was 37.4 mm on the control plates, 0 mm on the Tilt plates, and 7.7, 8.6, and 26.8 mm, on the Bravo, Quadris, and Top Cop plates, respectively ($P < 0.001$). We transferred the mycelial plugs from the Tilt treatments to untreated agar plates and examined them for 7 d for any sign of regrowth. No regrowth occurred. We concluded that Tilt was fungitoxic and that the other fungicides were moderately to strongly fungistatic to both fungi.

**Spray Chamber *In Vivo* Bioassay**. A laboratory spray chamber, calibrated to deliver 282 liters/ha using 3 TXVS-6 nozzles (2 on drops) at 2.2 kg/cm$^2$, and 4.8 km/h, was used to apply fungicides to whitefly-infested melon leaves (30 early 3rd instar nymphs per leaf; 4 replicated leaves per treatment), either 2 days before [2DB], on the same day (3 h before the fungi) [SD], or 2 days after [2DA] spray application of spore (aerial conidia) suspensions of *B. bassiana* and *P. fumosoroseus*. On SD, each leaf was sprayed with one 2-ml aliquot of spore suspension using a Potter spray tower. Each spore suspension was sprayed at a pressure of 0.7 kg/cm$^2$ using the fine spray nozzle (0.25 mm orifice diameter) provided with the tower. Dosages, estimated from spore counts taken from cover slips placed alongside the leaves in the spray arena of the Potter tower, were 808 ± 86 and 752 ± 188 spores/mm$^2$ for *B. bassiana* and *P. fumosoroseus*, respectively. Treated and control (0.01 % aqueous Tween 80) leaves were then isolated individually in vented plastic Petri dishes, and incubated for 24 h at 25ºC and 100% RH under a photophase of 16:8 (L:D) h. Thereafter, leaves were maintained under similar temperature and light regimes, but at 50-55% RH. The dishes of each treatment and control were incubated in isolation for the reason given above. Whiteflies were scored for mycosis 7 days after spore application. The angular values of proportion mycosis were analyzed by one-way ANOVA. Means were separated using the Tukey HSD test. Untransformed means are presented. In the *P. fumosoroseus* series, control mycosis (95.4%) was higher but not significantly different from mycosis in the 2DB, SD and 2DA Top Cop ($P = 0.598$), the 3 Quadris ($P = 0.077$), and the 3 Tilt ($P = 0.057$) treatments. Mycosis rate was 71.7, 49.1, and 65.8% in the 2DB, SD, and 2DA Bravo treatments, respectively [$P = 0.007$; Tukey test: control (a), 2DB (ab), SD (b), 2DA (b)]. In the *B. bassiana* series, control mycosis (81.2%) was significantly higher than mycosis in any of the 3 Bravo [$P < 0.001$; Tukey test: control (a), 2DB (26.7%b), SD (18.3%b), 2DA (45.0%b)] and any of the 3 Tilt [$P < 0.001$; Tukey test: control (a), 2DB (57.5%b), SD (41.7%b), 2DA (40.8%b)] treatments. Significant differences also were found in the Quadris treatments [$P = 0.001$; Tukey test: control (a), 2DB (65.8%ab), SD (63.3%bc), 2DA (45.8%c)] and in the Top Cop treatments [$P = 0.005$; Tukey test: control (a), 2DB (38.3%b), SD (48.3%b), 2DA (60.8%ab)]. At all 3 times of application, the fungicides were generally more compatible *in vivo* with *P. fumosoroseus* than with *B. bassiana*.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** Fall 1998

**Effects of *Beauveria bassiana and Paecilomyces fumosoroseus* on Two Lines of *Bemisia* whiteflies Both Reared on Two Different Host Plants**

Two lines (one from Arizona [AZ] and one from Texas [TX]) of *Bemisia* whiteflies were each reared in greenhouses for 6 generations on cotton 'Sure Gro 125' and cantaloupe melon 'Explorer'. *Beauveria bassiana* (strain GHA) and *Paecilomyces fumosoroseus* (strain 613) were applied to host plants infested with early 2nd-instars from the four cultures [AZ melon, AZ cotton, TX melon, and TX cotton] as 1-mi aliquots of conidial suspensions by using a Potter spray tower. Each test measured the effects of 3 dosages (rates) of conidia of each fungal strain using 3 replicated leaves per dosage (35--50 2nd-instars per leaf). Three replicated carrier (0.01% aqueous Tween 80) controls were included with each treatment. Following spray applications, the leaves were incubated at 25ºC, 50% RH and a 16 h photoperiod and were monitored daily for 10 d for whitefly mortality. The Abbott correction for control mortality was not used because only mycosis, not total mortality, in the $2^{nd}$ instars was considered. Proportions of mycosis in the eight fungus--whitefly culture--host plant combinations were arcsin square root transformed prior to ANOVA. When dosage effects in any of the 8 combinations were significant, means were separated using Tukey HSD test. Untransformed means are presented. Probit analysis was used to estimate the eight 10-d $LD_{50}$ values (conidia/$mm^2$), and other regression parameters.

***B. bassiana.*** There was no dosage effect on mycosis rates in the nymphs from the AZ cotton culture ($P$ = 0. 145; 49.2% mycosis at high dosage [940 conidia/$mm^2$]), nor in nymphs from the TX cotton culture ($P$ = 0.735; 47.6% mycosis at high dosage). Mycosis rates were 31.2 (Tukey test: b), 55.0 (b) and 83.9 (a)% in nymphs from the AZ melon culture at the low, medium and high dosage, respectively ($P$ = 0.004). No dosage effect was found in the mycosed nymphs from the TX melon culture ($P$ = 0.093; 72.5% mycosis at high dosage). The 10-d $LD_{50}$ values were I fold lower (=67 conidia/$mm^2$) in both melon series than in both cotton series (. 934 conidia/$mm^2$). Judged by the overlap between the confidence limits of the $LD_{50}$ values in both melon and both cotton cultures, the two lines of *Bemisia* nymphs were equally susceptible to *B. bassiana* when reared on either host plant. The lack of overlap among the melon and cotton $LD_{50}$ values indicated that both the AZ and TX lines of *Bemisia* were less susceptible to *B. bassiana* infection when reared on cotton than when reared on melon.

*P. fumosoroseus.* Only 28.5 (AZ cotton) and 12.1% (TX cotton) of nymphs died from mycosis after exposure to the high dosage (893 conidia/$mm^2$) of the fungus. No dosage effect was found in either series (AZ cotton: $P$ = 0.413; TX cotton: $P$ = 0.076). Mycosis rates in the AZ melon culture were 37.7 (Tukey test b), 71.1 (ab) and 82.8 (a)% at the low, medium and high dosage, respectively (dosage effect: $P$ = 0.04). In the TX melon culture, the rates were 31.0 (b), 67.3 (a) and 88.3 (a)% at the low, medium and high dosage, respectively (dosage effect: $P$ = 0.006). The 10-d $LD_{50}$ values for AZ melon and TX melon were 74 and 91 conida/$mm^2$, respectively and were not significant different (overlap of confidence limits). The two lines of *Bemisia* nymphs were therefore equally susceptible to *P. fumosoroseus* infection. The $LD_{50}$ values for AZ cotton and TX cotton could not be calculated, but were estimated to be >4,000 and >39.000 conidia/$mm^2$, respectively, which indicated that *Bemisia* reared on cotton was not susceptible to *P. fumosoroseus.*

We concluded that there was no line effect, but a strong host plant effect on *B. bassiana and P. fumosoroseus* pathogenicity to *Bemisia* nymphs. We hypothesize that gossypol or other allelochemical(s) might have been involved in antimicrobiosis on cotton leaves. The hypothesis is being tested.

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**Affiliation & Location:** [1]Department of Entomology, University of California, Riverside, [2]USDA, ARS, Western Cotton Research Lab, Phoenix, AZ.

**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** January - September, 1998

## Effect of Neem, Urea and Amitraz on Oviposition and Immature Development of *Bemisia argentifolii* (Homoptera: Aleyrodidae)

The effect of two formulations of neem seed extract, a crude extract from India and Azatin, a neem-based insecticide, urea and a mixture of neem seed extract + urea, were investigated as oviposition suppressants and larvicides against *Bemisia argentifolii* Bellows & Perring. Both seed and soil applications to cotton were tested. Pre-treatment of cotton seeds by neem seed extract did not significantly suppress oviposition but it was suppressed when it was applied as a soil treatment. However, both seed and soil applications of neem seed extract produced significant mortality of immatures leading to reduced emergence of adults. Azatin was effective in suppression of oviposition as well as in inducing larval mortality by both methods of application. Treatment of cotton seeds by urea was effective in reducing oviposition but was ineffective in a soil application. Although treatment of seeds or soil by urea was not toxic to immatures by itself, a mixture of neem seed extract + urea was more effective in the suppression of oviposition and immature mortality, thus reducing the numbers of adult whiteflies that emerged.

Foliar applications of neem seed extract and Amitraz, a non-chlorinated formamadine, were investigated in another series of tests of their effects on oviposition and development of whitefly immatures. Both compounds effectively suppressed oviposition and induced mortality of immatures. Ovicidal activity of Amitraz appeared to occur late in embryonic development, or even post-embryonically during eclosion. These results suggest that neem or Amitraz may serve as alternative chemicals to conventional insecticides in a resistance management program for whiteflies.

**Investigator's Name(s):** Philip A. Stansly.

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**Research & Implementation Area:** Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods.

**Dates Covered by the Report:** March - June 1998

### Control of Silverleaf Whitefly and Turnip Aphid on Collards with Foliar and Soil-Applied Systemic Insecticides

The grower may have the option to apply systemic insecticides to the foliage or the soil. The objective of this study was to compare the efficacy of these two application methods against the silverleaf whitefly (SLF). Two sets of 3 of fertilized beds 32 inch wide, 240 ft long were fumigated with 67/33% methyl bromide/chloropicrin, covered with black polyethylene film and drip irrigated. The 2 sets of 3 rows were separated by a 15 ft drive middle and the middle row of each set was planted with collard seedlings on 12 January as a source of pest inoculum. Greenhouse raised collard seedlings were planted in the remaining 4 beds at 18-inch spacing on 13 February. Each bed was divided into 7 plots 34 ft long to which 6 treatments and untreated check were assigned in a RCB design with 4 replications. Soil treatments were applied in 10 ml water to each plant hole on 06 Mar. Foliar treatments were initiated 28 April with a high clearance sprayer utilizing a hydraulic pump operating at 200 psi and delivering the spray at a rate of 33 GPA through one drop boom on each side of the row and one overhead, each equipped with 1 yellow hollow cone Albuz7 nozzle. These applications included 2 of CGA-215 and CGA293 on 28 Apr and 15 May and 6 each week of acetamiprid and Provado beginning 28 Apr.. Silwet at 0.25% V/V was added to the tank with all sprays. Aphids and adult whiteflies were sampled in soil-treated and check plots on 2 whole leaves (one upper 18 x 25 cm and one lower 29 x 34 cm, April 7 and 20 respectively) on each plant, 10 plants/plot. Most aphids were found on the upper leaf and whiteflies on the lower leaf. Sampling for adult whiteflies in all plots began 01 May using a 9 X 13 inch metal cake pan (Abeat pan@) painted black and covered with a 10% detergent/vegetable oil mixture. Total number of adults captured from three beats on one side of 3 separate plants was counted as a sub-sample with 4 sub-samples collected/plot. Immature whiteflies were counted under a stereoscopic microscope in the laboratory on 4 leaves (1,000cm$^2$)/plot collected from the field on 05 May and 14 May. Also on 14 May spider mite infestation was evaluated on 4 leaves/plot by rating on a scale of 0 to 3 where 0 indicated no mites, 1 indicated 1-15, 2 indicated 16-45, and 3 indicated 45> were counted/leaf.

Turnip aphids were present on 7 April but disappeared later following the appearance of numerous coccinellids. Both aphid and whitefly numbers were significantly lower in soil-treated plots on 7 April compared to the check with no significant difference between treatments. The same pattern was seen with whiteflies on 20 April. On all subsequent dates, fewer whitefly adults were observed on treated plants in all plots compared to the check except on 04 June for plants treated with CGA-215. There were never any significant differences between soil treatments in number of adults although the overall mean was slightly lower with Admire. Neither were there any significant differences between foliar CGA-293 and acetamiprid although the overall mean for the latter was numerically lower. CGA-215 provided the least protection against adults, significantly less than acetamiprid on 5 sample dates and overall dates. Acetamiprid provided significantly better control of adults than Provado on 2 sample dates, and fewer adults were seen on plants sprayed with Provado compared to CGA-215 on one sample date. Fewer adults were seen plants treated by soil application compared to foliar application through14 May (68 DAT) and there were still significantly fewer adults soil-treated plants through 17 June (103 DAT) than the control. On 5 May, fewest eggs or small nymphs were seen on plants treated with CGA-293 and Admire, though not significantly less than all other treatments except Provado and the check (eggs) or the same two and acetamiprid (small nymphs). On that date fewest large nymphs and pupae were seen on plants treated with Admire, though not significantly less than other treatments except the check and Provado (pupae) or Provado and acetamiprid (large nymphs). No eggs or small nymphs were found on Provado or CGA-293 soil-treated plants on 14 May and all treatments had fewer eggs than the check except for CGA-215. Fewer large nymphs as well were seen on all treated plants compared to the check except for CGA-215, and there were no pupae on Admire-treated plants although differences were not significant except for the untreated check. The proportion of large nymphs and pupae that were parasitized was not diminished by any treatment, and might have been enhanced although differences were not significant. Spider mites were not significantly affected by any treatment. In summary, imidacloprid provided excellent control of both adult and immature whiteflies when soil-applied but did not function well when applied to the plant.  CGA-293 functioned well in both modes, comparable to Admire when soil-applied and to acetamiprid when applied as a foliar.  These results were largely consistent with those obtained last year on tomato.

## Research Summary

## Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods

Compiled by James Brazzle

### Current Research Activities

Chemical control continues to be a very important part of silverleaf whitefly management in most agricultural systems. The need for chemical control options results in the need for integrated and resistance management programs, and continued investigation of ways to increase the efficacy of chemical control through the development of new chemistries and application methods.

The uses of systemic insecticides and insect growth regulators have lead to a lessening of crop losses due to whitefly while opening the door to a greater role for biological control. New systemic insecticides are in development such as CGA-293 and the foliar use of acetamiprid looks promising. Progress to integrate chemical controls continues with an emphasis on the integration of systemic and biorational products with one another and various natural enemies. New biorational products reported in this year's report includes sugar esters, particle films and bitterwood extracts. Sugar esters were most effective on large nymphs while bitterwood studies focused on adult suppression. Products that trigger natural plant defenses (systemic induced resistance), have been studied to a limited degree and appear to suppress the exponential growth of a whitefly population.

Entomapathic fungi, *Beauvaria bassiana* and *Paecilomyces fumosoroseus*, and azadirachtin continue to be studied with more advanced formulations and as a part of an integrated program. For example, studies reported include the impact of host plant on dose response, the potential antimicrobiosis of cotton allellochemicals and the impact of *B. bassiana* on non-targets, specifically predators. In addition, application methods may provide opportunities to increase the efficacy of these biorationals. Work with application methods suggests the importance of higher volumes (30 GPA) and pressures to increase coverage. The potential of the systemic action of neem is also reported. These studies set out to increase our understanding of biorationals in an effort to characterize their fit into diverse agricultural production systems and increase efficacy.

Given the present and future dependence on chemical control, monitoring and management of insecticide resistance continues to be a primary focus. Studies focusing on our basic understanding of resistance have examined the genetics and biochemistry of resistance and cross-resistance concentrating on acetylcholinesterase and chloronictinoids. Baselines have and continue to be established for insect growth regulators and systemics. Continued work on new chemistries is important in detecting shifts early in a products use. The establishment of resistant colonies to various classes of insecticides has increased providing resistant specimens for use in resistance studies.

The development of resistance management programs at the grower level has had a significant impact as a technology transfer item. Resistance monitoring and associated studies require a reliable bioassay procedure that is sensitive to changes in dose-mortality response. These programs began with the development of quick reliable field monitoring tools allowing researchers to characterize populations throughout southwestern growing regions. Early characterization quickly pointed to the complexity surrounding resistance in diverse agroecosystems and the need to sample several populations to understand changes in susceptibility to different modes of action. Attributes of a particular ecosystem such as cropping patterns, local insecticide use, influence of refuges, and cultural production practices (e.g. fertilization) all potentially impact the magnitude and speed of resistance development. Increasing our understanding of resistance management in turn has provided growers with tools to make informed decisions about insecticide use. Some programs have gone as far as putting bioassay results from various regions on a web page. Work continues to better characterize diverse agroecosystems related to resistance development.

The optimum resistance management program will incorporate vertical and horizontal integration supported by sound science. Work in California has resulted in a vertically integrated program that examines all pests in the cotton system understanding the ripple effect managing one pest has on another. Arizona is working to horizontally integrate by linking whitefly resistance management programs across commodities. These programs while very complex have been well received and as they mature will likely look to one another to bring vertical and horizontal integration together. The foundation of these programs is good science, much of which is credited to this national whitefly group, and its future success will depend on continued leadership, strong science, and cooperation.

**Table C. Chemical Control, Biopesticides, Resistance Management, and Application Methods.**

| Research Approaches[a] | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Improve insecticide efficacy:** | | | | |
| **Develop, test, and assist in the registration of insecticides, biorationals, and natural products.** | Develop new chemistries and natural products. Develop improved techniques for evaluating efficacy of insecticides. Support registration of desirable new products by providing information to regulatory agencies. | X | | New studies reported in this area in 1997 = 39. New biopesticides like *Petunia* extract and *Melia* extract tested. New biorationals tested or reported on included benzyl phenal urea napthaphenol and antibiotics (to act against symbiotic bacteria). |
| **Develop improved methods of application including formulation and delivery of materials to improve control.** | Develop spray systems for better underleaf coverage. Evaluate rates, timing, placement in relation to efficacy. Consider formulation, UV protectants, and other means to improve efficacy. Develop improved methods to evaluate application efficacy. Field test under commercial conditions for technology transfer. | X | | New studies = 10. Thermal fogger evaluated for greenhouse use. However, a comparison of five-sprayers in the field trials showed no significant differences between hydraulic, air-assist and electrostatic technology. |
| **Conserve insecticide efficacy:** | | | | |
| **Relate action thresholds to insecticide usage patterns.** | Refine action thresholds based on insecticide efficacy and input from other control strategies. | X | | New studies = 8. Cost-benefit study of IPM system in cotton. Life table approach to evaluate impact of mortality factors initiated. Training effort to extend threshold information to growers in Arizona. |
| **Elucidate the role of genetic, biochemical and ecological factors leading to insecticide resistance.** | Establish whitefly strains resistant and susceptible to various classes of insecticide. Conduct studies to determine the genetics and biochemistry of resistance and cross resistance to different classes of insecticide. | X | | New studies = 4. Imidacloprid binding site elucidated. Studies completed on stability of resistance in *Bemisia* including agricultural and ecological factors. |

**Table C. Chemical Control, Biopesticides, Resistance Management, and Application Methods. (Continued)**

| Research Approaches[a] | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Improve insecticide efficacy:** | | | | |
| **Improve techniques for monitoring resistance.** | Establish baseline data on toxogenic responses of whitefly populations to new insecticides. | X | | New studies = 9. Bioassays developed for testing sensitivity to imidacloprid. Baseline data obtained on sensitivity to imidacloprid and IGRs pyriproxyfen and buprofazin. |
| **Develop, evaluate and refine resistance management systems.** | Evaluate the effects of mixtures and rotations of new and old chemistries to mitigate selection for resistance. | X | | New studies = 14. Area-wide plans for management of resistance refined in Arizona and California. Large-scale trials of resistance management strategies conducted. |
| **Integrate chemical control with other tactics.** | Evaluate selectivity of synthetic insecticides and natural products to key whitefly natural enemies. | X | | New studies = 10, including laboratory and field studies on compatibility with whitefly natural enemies. Also a study on effects of pyrethroids on anitbiotic factors bred into crops. |

[a] See Table A for complementary research on thresholds.
[a] See Table B for complementary research on virus/vector interactions.
[a] See Table D for complementary research on biological control.
[b] See Table E and F for complementary research on systems management.

**Table C. Chemical Control, Biopesticides, Resistance Management, and Application Methods.**

| Research Approaches[a] | Year 2 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Improve insecticide efficacy:** | | | | |
| **Develop, test, and assist in the registration of insecticides, biorationals, and natural products.** | Determine new modes of action of effective materials. Elucidate biochemical pathways of synthesis and degradation of natural products. | X | | (1) Section 3 registration of IGRs. (2) Section 18's supported, acetamiprid summer '99. (3) progress evaluating soil applied modes of action, sugar esters and entomopathic fungi., integration of biorationals and conventional chemistries. Need to evaluate future impact of FQPA. References 40, 69, 71, 78, 81, 103, 104, 108, 145, 165, 166, 167, 168, 180, 186, 187, 188, 212, 220, 262, 263, 273, 274, 297 |
| **Develop improved methods of application including formulation and delivery of materials to improve control.** | Develop spray systems for better underleaf coverage. Evaluate rates, timing, placement in relation to efficacy. Consider formulation, UV protectants, and other means to improve efficacy. Develop improved methods to evaluate application efficacy. Field test under commercial conditions for technology transfer. | X | | Akey's work with high PSI systems, increasing stability for azadiractin and utilizing digital photographs to evaluate application efficacy. References 47, 131, 139 |
| **Conserve insecticide efficacy:** | | | | |
| **Relate action thresholds to insecticide usage patterns.** | Refine action thresholds based on insecticide efficacy and input from other control strategies. | X | | Mint sampling plan/thresholds, distribution patterns validated, References 35, 125, 212, 317 |

**Table C. Chemical Control, Biopesticides, Resistance Management, and Application Methods. (Continued)**

| Research Approaches[a] | Year 2 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Elucidate the role of genetic, biochemical and ecological factors leading to insecticide resistance.** | Establish whitefly strains resistant and susceptible to various classes of insecticide. Conduct studies to determine the genetics and biochemistry of resistance and cross resistance to different classes of insecticide. Evaluate the role of refuge habitats (weeds, tolerant crops, urban areas) to assure input of susceptible genes in whitefly population. | X | | Resistant colonies exist to endosulfan, chlorpyrifos, imidacloprid, bifenthrin; genetic and biochemistry studies are concentrated on acetylcholinesterase (Byrne) and nicotinyls; cross resistance being studied between nicotinyls and neonicotinyls. Impact of ecological factors such as nutrition, host plant response, local cropping patterns are being studied. Role of alfalfa as a refuge has been evaluated. References 18, 22, 46, |

**Table C. Chemical Control, Biopesticides, Resistance Management, and Application Methods. (Continued)**

| Research Approaches[a] | Year 2 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Improve insecticide efficacy:** | | | | |
| **Improve techniques for monitoring resistance.** | Establish baseline data on toxogenic responses of whitefly populations to new insecticides. Expand comparative studies of resistance levels in diverse agro-ecosystems. Evaluate relationship between monitoring results and field efficacy. | X | | Baselines have and are being established for IGRs and systemic insecticides. Work in Cal. & Arizona ongoing to evaluate regional resistance management techniques which include four distinct agro-ecosystems. Work in ornamentals is increasing. Relationships between monitoring results and field failure are primarily anecdotal at this time. References 140, 227, 286, 314 |
| **Develop, evaluate and refine resistance management systems.** | Evaluate the effects of mixtures and rotations of new and old chemistries to mitigate selection for resistance. Develop methods to evaluate and augment the beneficial influence of refuges as sources of susceptible genes to the population pool. | X | | Prabhaker et al. in press. Studies to increase horizontal integration of resistance management programs are addressing influence of refuges in diverse agro-ecosystems. References 20, 47, 76, 77, 235, 245, 284, 310 |
| **Integrate chemical control with other tactics.** | Evaluate selectivity of synthetic insecticides and natural products to key whitefly natural enemies. Test compatibility of biological control with selective synthetic or natural product insecticides as required. | X | | Most efficacy trials include a compatibility evaluation, selectivity evaluations include systemics, entomopathic fungi; life tables are contributing to our understanding here. References 7, 9, 10, 11, 13, 24, 25, 27, 31, 32, 37, 38, 49, 70, 89, 90, 93, 96, 97, 98, 105, 110, 129, 147, 149, 153, 160, 169, 174, 194, 200, 247 |

[a] See Table A for complementary research on thresholds.
[a] See Table B for complementary research on virus/vector interactions.
[a] See Table D for complementary research on biological control.
[b] See Table E and F for complementary research on systems management.

**Reports of Research Progress**

**Section D: Natural Enemy Ecology and Biological Control**
Co-Chairs: Charles Pickett and James Hagler

**Investigator's Name(s):** D. H. Akey & T. J. Henneberry.

**Affiliation & Location:** USDA, ARS, Western Cotton Research Laboratory, Phoenix, AZ 85040-8803.

**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** June - October 1998

## Use of the Entomopathogenic Fungi, *Beauveria bassiana*, and *Paecilomyces fumosoroseus as* Biorational Agents Against the Silverleaf Whitefly (SLWF), *Bemisia argentifolii*, in Field Trials in Upland Cotton

Deltapine NuCOTN 33[B] was planted and furrow irrigated in plots 109 ft. in length and 12 rows across (40-in. rows). Plots were separated by 4 fallow rows and 20 ft. alleys. *Beauveria bassiana* as Naturalis®, Troy Biosciences Inc. at 10 oz. Product/ac, 2.3x $10^7$ conidiia/ml was used at full rate as single product applications. *Beauveria bassiana* as Mycotrol®, Mycotech Corp., 0.5 lbs./ac, 2 x $10^{13}$ spores/lb. was used at full rate as single product applications. *Paecilomyces fumosoroseus* PFR-97® Thermo Trilogy Corp., 0.025 lbs. / gal., 1x $10^9$ CFU (spores)/ gm equivalent 20% product was used. These treatments were part of a 12-treatment random block design that included a "Best Agricultural Practice regime", embedded controls, and a 1-ac block control.

Eggs, small nymphs, and large nymphs were sampled from leaves taken from 5 plants per plot, from the fifth main-stem leaf down from the first expanded terminal leaf. Each sample was counted from a 1-in. disk taken between the main leave stem and the next lateral vein. Adults were sampled from 30 leaves/plot, same location using a binomial decision of counting a leaf as positive if 3 or more adults were present. Weekly sweeps were taken in all plots for predators, parasites, and *Lygus*. Applications were made by ground with 5 nozzles/row; 1 overhead, and 2 swivel nozzles angled upward on a drop on each side of the row. Sprays were applied at 250 psi and 30 gal./ac.

The 1998 cotton season was a poor production year. The SLWF population reached action threshold (Univ. AZ recommendations) between July 27- Aug.6, 1998. Two sprays were applied (8-day period), then the SLWF population dropped precipitously and did not recover before the end of the cotton season. Against eggs, formulations of *Beauveria bassiana* had efficacies of 41 and 23 % as Naturalis L®and Mycotrol®, respectively; PFR-97® had an efficacy of 30 %. Against small nymphs, formulations of *Beauveria bassiana* had efficacies of 6 and 19 % as Naturalis L®and Mycotrol®, respectively; PFR-97® had an efficacy of 24 %. Against large nymphs, formulations of *Beauveria bassiana* had efficacies of 28 and 8 % as Naturalis L®and Mycotrol®, respectively; PFR-97® had an efficacy of 4 %. Despite these low efficacy rates, the SLWF populations remained below action thresholds. Only egg efficacies were statistically significant by ANOVA and LSD ($P < 05$). Buprofezin (Applaud™ 70 WP, AgrEvo, 0.35 lb. AI/ac) was the first BAP treatment was to be applied. Because of the unusual nature of the SLWF population decline, no other BAP treatments were made. Buprofezin (Applaud™ 70 WP, AgrEvo, 0.35 lb. AI/ac) was used as a standard and had egg, small nymphs, and large nymph efficacies of 28, 37, 38 % respectively.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** January 1, 1997 - December 31, 1998

## Successful Rearing of Parasitoid Wasps on *Bemisia argentifolii* Cultured on Artificial Diet

We have demonstrated that *Encarsia formosa* and *Encarsia pergandiella* parasitic wasps can successfully oviposit and develop in whitefly larvae maintained on liquid artificial diet. *Eretmocerus mundus*, which oviposit underneath their host, demonstrated typical oviposition behavior on these larvae, but no progeny developed. We presume that oviposition never took place because host larvae were too tightly secured to the artificial substrate, preventing the wasp's ovipositor to access the underside of the *Bemisia* larvae.

We have subsequently concentrated our efforts on rearing *E. formosa* as this species is a commercially available parasitoid sold for managing whitefly pests of greenhouse crops. Additionally, *E. formosa* is uniparental, making it more convenient for experimentation.

*E. formosa* was obtained from the USDA Mission, TX Plant Protection Center, and used to establish a laboratory colony on *B. argentifolii* reared on tomato, cotton and collards. Parasitoid pupae were individually removed from leaves and surface sterilized on filters, using a regime of 70% ethanol followed by 3 min in 10% chlorox solution. Pupae were rinsed with sterile water and confined to sterile petri dishes until emergence. Emerged wasps were chilled and moved to feeders containing artificial diet (Jancovich et al., 1997, Feeding chamber and diet for culture of nymphal *Bemisia argentifolii*. J. Econ. Entomol. 90: 628-633) on which whitefly larvae had attained third or fourth instar. Wasps were confined to the inner chamber containing the whitefly larvae using sterile slides. After 48 hr, chambers were again chilled and wasps removed. Chambers were held at 25 $^{o}$C and observed for evidence of parasitism.

Parasitism, as indicated by dark oviposition marks, was observed on nearly all exposed hosts after 48 hr. Successful emergence of adult wasps occurred 15-22 days. Wasps continued to emerge over a period of ca. 5 days. On most feeders, nearly all living whitefly larvae of appropriate age (third instar or beyond) were parasitized. As of December 1, 1998, at least 50 *E. formosa* have been produced on these *Bemisia* produced on artificial diet, and emerged adult females have been transferred to further feeders and to plants to assess parasitic efficiency of the adults produced on the artificial system. We believe this represents the first report of production of parasitoid wasps on whiteflies on artificial feeding system.

The major problem encountered in this process is fungal contamination. Because the chambers must be handled several times during the parasitism process, they frequently become contaminated with fungi which quickly overgrow the chamber. Subjecting the chambers to sterilizing ultraviolet radiation after each handling procedure reduces contamination somewhat. We are currently attempting to reduce or eliminate fungal contamination, to shorten the development time by improvements in whitefly diet, and to assess the reproductive success of wasps produced by this technique.

**Investigator's Name(s):** S. M. Greenberg[1], Walker A. Jones[2], B. C. Legaspi[1], Jr., & W. C. Warfield[2].

**Affiliation & Location:** [1]Joint affiliation: Beneficial Insects Research Unit, Kika de la Garza Subtropical Agricultural Research Center, USDA-ARS and Texas Agricultural Experiment Station, Weslaco, TX; [2]Beneficial Insects Research Unit, Kika de la Garza Subtropical Agricultural Research Center, USDA-ARS, Weslaco, TX.

**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1998

## Interaction Between *Encarsia pergandiella* (Hymenoptera: Aphelinidae) and its Host *Bemisia argentifolii* (Homoptera: Aleyrodidae): Effects of Parasitoid Densities and Host-Parasitoid Ratios

Laboratory experiments were conducted to measure the functional response of *Encarsia pergandiella* Howard (Hymenoptera: Aphelinidae) to *Bemisia argentifolii* Bellows and Perring (Homoptera: Aleyrodidae) and the effects of different densities of parasitoids on mutual interference. When host density was held constant (100 third instars) and parasitoid density was varied from at 1, 5, to 15 females, the percentage of total host mortality (parasitized + desiccated nymphs) was significantly lower at the lower parasitoid densities. The number of parasitized host nymphs per parasitoid female decreased 15-fold with increasing parasitoid density from 1 to 15. The interference between parasitoids, which detracts from their searching efficiency, increased as parasitoid density increased. The emergence rate, development time, and body lengths of progeny were significantly greater at parasitoid densities of 1 and 5 than at 15. When the number of parasitoids was held constant (n = 5) and the number of hosts varied (5, 25, 50, 100, and 250), the total percentage of nymph mortality decreased from 91.3% (1 : 1 parasitoid - host ratio) to 19.1% (1 : 50). The data could be described using a Type 11 functional response curve. To summarize and compare the effects of parasitoid - host ratios, we propose a generalized index of efficacy, calculated by multiplying the proportions of total host mortality and emergence of parasitoids under each treatment. The index showed that the most efficient parasitoid - host ratio was 1: 10.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1998

## The Effect of Varying Ratios of *Bemisia argentifolii* (Homoptera: Aleyrodidae) and *Eretmocerus mundus* (Hymenoptera: Aphelinidae) on Parasitism

We investigated the effects of different host: parasitoid ratios on the efficacy of the parasitoid *Eretmocerus mundus* Mercet (Hymenoptera: Aphelinidae) attacking the silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring (Homoptera: Aleyrodidae). When host density was held constant (100 second instars) and parasitoid density increased from 1 to 15 females, the percentage of total host mortality (parasitized + desiccated nymphs) was significantly lower at low parasitoid densities. In this same experiment, the number of host nymphs killed and female parasitoid progeny per female decreased 3.6 and 20.4 times, respectively. The emergence rate, sex ratio, development time, longevity, and body lengths of progeny were significantly higher at the lowest parasitoid density. When the number of hosts was increased from 5 to 250, and parasitoid density was held constant, the total percentage of nymph mortality decreased 1.6 times. The percentage of desiccated nymphs at the lowest host density (65.7%) was significantly greater than at other densities while the percentage of parasitism at the lowest host density (34.3%) was significantly lower. The data could be described using a Type I functional response curve. We propose a generalized index of efficacy (GIE) to summarize and compare the total effects of parasitoid - host ratios. This index showed that the most efficient ratio was one parasitoid female per ten second instar host nymphs.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1998

## Effects of Host Plant and Whitefly Species on Parasitoid Biology

Biological parameters were measured for the native *Encarsia pergandiella* Howard and the exotic *Eretmocerus mundus* Mercet when reared on 3 whitefly genotypes maintained on 2 host plant species. The 3 whitefly cultures were: *Bemisia argentifolii* Bellows and Perring (= *B. tabaci,* Biotype B), *Trialeurodes vaporariorum* (lab culture from Ithaca, NY, designated "A"), and a "wild" culture of *T. vaporariorum* collected locally from weeds (designated "B"). The 3 whiteflies were each reared on excised leaves of cotton and green bean placed in floral aquapik tubes filled with hydroponic solution, thus producing a 2 x 3 x 2 factorial. Tests were conducted at 25EC, 55% RH, with a 16 : 8 (L : D) h regime. Two female parasitoids were exposed to 100 whitefly nymphs for 3 h (2nd instars for *E. mundus;* 3rd for *E. pergandiella ).* The parasitization and emergence rates of both parasitoids were significantly higher on *B. argentifolii* reared on cotton or bean than those on *T. vaporariorum* "A"; data for *T. vaporariorum* "B" were intermediate. These indices for *E. pergandiella* were higher and the differences between them from host plants and whitefly species were less pronounced than by *E. mundus.* Developmental time of both *E. mundus and E. pergandiella* was significantly faster after parasitizing *B. argentifolii* maintained on cotton than on bean. However, *E. pergandiella* developed significantly faster when parasitizing *T. vaporariorum* "A" on bean than on cotton; no other whitefly - plant combinations produced significant differences in parasitoid growth rate. *E. mundus* produced a significantly higher percentage of female progeny when parasitizing *B. argentifolii* reared on cotton, but produced significantly fewer females when attacking *T. vaporariorum* "A" on cotton, compared to the same whitefly hosts maintained on bean. Both parasitoid species progeny lived significantly longer after developing on *B. argentifolii* maintained on cotton than on bean. However, when both *E. mundus and E. pergandiella* developed on *T. vaporariorum* "A" reared on bean, the resulting adults lived significantly longer than those that developed on the same hosts reared on cotton. The other whitefly-host plant combinations yielded no significant differences in progeny longevity. Significant differences in the size of female progeny corresponded directly to the significant differences in longevity. Generally, *B. argentifolii* was a better host for parasitoids when cotton was the host plant, whereas the laboratory strain of *T. vaporariorum* was a more suitable parasitoid host if reared on green bean.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** March 1998 - December 1998

## Evaluation of Parasitoid Dispersal Patterns by Mark-Release-Recapture

Laboratory studies were conducted to evaluate the efficacy of marking whitefly parasitoids with a protein prior to enzyme-linked immunosorbent assay (ELISA). Data indicated that this marking technique is superior to conventional marking techniques. In the field, adult *Eretmocerus* from the United Arab Emirates were internally marked by feeding them a honey solution spiked with either rabbit protein or chicken protein. The parasitoids marked with the rabbit protein were released at the center of a cotton field while those marked with chicken protein were released at the center of an adjacent cantaloupe field. The parasitoids were then recaptured every 4 to 6 hours for 72 hours after release using passive suction vacuum traps (100 to 200/collection) located in the two fields. Every parasitoid that was recaptured was assayed by ELISA for the presence of either the rabbit protein or chicken protein marker in order to determine its point of origin. These data are currently being analyzed and summarized to determine the inter-crop dispersal patterns of this parasitoid. The preliminary results look promising.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** January - December 1998

## Evaluation of Citrus as an Overwintering Host of *Eretmocerus* Parasitizing *Bemisia*

Surveys by the California Department of Food & Agriculture and the University of California identified citrus orchards (especially Washington navel and Valencia orange cultivars) as potential overwintering refuges in the San Joaquin Valley for silverleaf whiteflies which could reinfest field crops the following spring. In order to assess the value of native and introduced parasitoids in helping to suppress overwintering whitefly populations in citrus, studies were initiated in the fall of 1997 and concluded in spring 1998.

A. *Evaluation of citrus as a developmental host for exotic and native parasitoids:* In replicated outdoor cage studies in Brawley, Washington navel cv. Lane Late seedlings were used as hosts for cohorts of *Bemisia argentifolii* nymphs. Five 6x6x6 ft cages per parasitoid species, each containing 4 citrus seedlings with new foliage, were inoculated with whiteflies. When populations of 2nd and 3rd instar whiteflies were present, 100 females each of *Eretmocerus mundus* ex Spain (MBCL #M92014), *Eret. hayati* (M95012 ex Pakistan), *Eret. emiratus* (M95104 ex UAE), *Eret.* sp. ex Ethiopea (M96076) and native *Eret. eremicus* were introduced into the cages to oviposit and host-feed on whiteflies. Parasitoids were obtained from cultures maintained by USDA, APHIS Mission Biological Control Center in Mission, TX, the CDFA Biological Control Program in Sacramento and Novartis BCM/Bunting USA. Sampling was begun late in December 1997, and the mean number of F1 progeny per female of each species was determined. All of the *Eretmocerus* species in the study successfully parasitized and developed in *Bemisia* nymphs on citrus. The average number of progeny per female was between 2.1 and 5.9, considerably less than produced on favored hosts such as cantaloupe in warmer weather. The between-species differences in mean number of progeny were not significant in this study.

B. *Evaluation of citrus in the San Joaquin Valley as an overwintering refuge for exotic and native parasitoids:* In late October, after migrating whiteflies from nearby cotton established fall populations on citrus, organdy sleeve cages were placed over whitefly-infested terminal branches of established citrus trees in the San Joaquin Valley orchards. Replicated releases were made at one site each in Tulare and Kern counties. Releases were not made at a third site that had been selected due to high native predation resulting in nearly total loss of whitefly populations. Ten - twenty female *Eretmocerus mundus* ex Spain (M92014) or Israel (M94120), *Eret. hayati* ex Pakistan (M95012), *Eret. emiratus* ex UAE (M95104) or native *Eret. eremicus* (ex SW desert US) were introduced per sleeve to attack immature whiteflies. Sleeves were removed after 7 days. Reproduction and overwintering survival of the parasitoids was assessed after F1 adults began to emerge in the spring of 1998. Mortality of whitefly eggs and nymphs was very high at each site. The average number of F1 progeny per female parent was between 0.05 and 0.283. No significant differences between species were found due to the low numbers and high variability between sleeves. Our observations suggested that predation of whiteflies in the orchards and developmental mortality on citrus were key factors in reducing whitefly populations over the winter, and predation probably also impacted the survival of parasitized whiteflies.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** January - October 1998

## Yellow Sticky Trap Catches of *Bemisia* Parasitoids and Their Relation to Field Populations

Yellow sticky traps are sometimes used to survey for parasitoids, including those attacking *Bemisia*. Because there is a lack of knowledge regarding the relationship between numbers trapped and actual field populations, studies were conducted in 1997-98 with crop plants to examine the correlation of sticky trap catches with actual parasitoid populations in the associated crop.

Traps were placed in collard (summer-fall 1997) & cowpea (summer-fall 1998) on an experimental farm in Charleston, SC and in commercial organic fields of broccoli (fall-winter 1997-98) and spring cantaloupe & watermelon (spring 1998) in the Imperial Valley, CA. To ensure parasitoid populations would be present, several million exotic *Eretmocerus mundus* (ex Spain, M92014) were released during a 3-week period early in the season in the commercial broccoli, and several million *E. emiratus* (ex UAE, M95104) were released for several weeks in the commercial melon fields in the Imperial Valley. Releases were made when susceptible stages of the whitefly were detectable until several weeks prior to first placement of sticky traps. Grids of horizontally-oriented traps were placed at canopy level in crops & replaced weekly, and weekly samples of leaves were collected and numbers of parasitized whiteflies counted.

Steadily declining whitefly numbers throughout the fall-winter broccoli in CA and the summer collard in SC led to extremely low whitefly and undetectable parasitoid populations by the time the remnants of the parasitized generation matured in broccoli in Imperial Valley. Most whiteflies appear to have been lost on decomposing leaves dropped from the plants. Sampling from cowpea was concluded in October 98 and samples were frozen and await processing.

In spring melons in CA, whitefly and parasitoid populations increased throughout the season, and were more numerous on cantaloupe than watermelon. *Bemisia* adults in cantaloupe were trapped in greater numbers on the lower surface of sticky traps early in the season, but this was reversed during the last weeks as melons became unsuitable as a host. In watermelon, whiteflies were initially trapped on both sides equally but as the crop matured, greater numbers were trapped on top. In contrast, downward-facing trap surfaces consistently captured ca. 5-10 times more *Eretmocerus* than upwards-facing traps. This suggests that most of the parasitoids trapped probably came from the study site rather than migrating into the fields from elsewhere. Exotic *Eretmocerus* far outnumbered native *Eret. eremicus* and *Encarsia spp.* on the traps. The mean number of *Eretmocerus* per trap in cantaloupe ranged from ca. 4 early in the season to a high of nearly 50 per trap near crop maturity. The ratio of females to males on traps remained about 2:1 throughout the 7-week sampling period. The trend throughout the season of increasing numbers of *Eretmocerus* on traps paralleled the increase in numbers of *Eretmocerus* counted on leaf samples. The mean number of 4th instar whiteflies on leaves peaked at 70.05 / leaf by the end of the season. Throughout the season, 1/4 to 1/2 of all 4th instars were visibly parasitized by *Eretmocerus* (a conservative estimate which does not include parasitism by young *Eretmocerus* larvae and unhatched eggs).

The numbers of *Eretmocerus* caught by yellow sticky traps in melon fields were consistent and similar in trend to numbers on leaf samples, which suggests that sticky traps placed within crops may be used to 1) provide a reasonable estimation of the trend in parasitoid populations at a particular site, and 2) to detect the presence of these parasitoids at specific locations.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** January 1, 1998 - December 31, 1999

## Interference Competition Between a Primary Parasitoid and an Autoparasitoid on *Bemisia tabaci*

Recent theory has revived the controversy surrounding the importance of interspecific competition between natural enemies on regulation of pest populations. In particular, natural enemies that attack both the pest and their competitor ('intraguild predators') are predicted to displace their competitors and reduce regulation of the pest. Autoparasitoids are a unique type of intraguild predator. In these aphelinid wasps, females develop as primary parasitoids of a homopteran host, while males develop as hyperparasitoids, attacking either conspecific females or other primary parasitoids. While autoparasitoids have been used successfully in classical biological control, their unusual life history has made them controversial candidates for introduction.

In laboratory experiments we examined the interactions between two parasitoids of the sweetpotato whitefly. *Eretmocerus eremicus* Rose & Zolnerowich is a primary parasitoid that is native to the Southwestern U.S., and *Encarsia transvena* (Timberlake) is an exotic autoparasitoid widely released in the Southwest and now establishing in California. We used the population of *E. transvena* originally collected in Murcia, Spain. Our experiments demonstrated that *E. transvena* females did not discriminate among suitable stages of conspecific and *E. eremicus* immatures as hosts for male eggs. However, the interval during which *E. eremicus* immatures were suitable for parasitism was much longer, suggesting that the primary parasitoid was more vulnerable to parasitism than conspecific *E. transvena.* Another set of experiments indicated that *E. transvena* won competitions with *E. eremicus* on the whitefly host.

Field experiments were conducted to examine the outcome of competition: caged cotton plants with 1) whiteflies only (Control), 2) *E. eremicus* alone, 3) *E. transvena* alone, or 4) both parasitoids together were censused in 1997 and 1998. In both years, the densities of the autoparasitoid, *E. transvena* were not significantly different in the '*E. transvena* alone' and the 'both' treatments. In contrast, in both years the densities of '*E. eremicus'* were significantly reduced in the 'both' treatment, compared to the '*E. eremicus* alone.' The effects of interspecific competition on the densities of the parasitoids were consistent with the laboratory experiments suggesting dominance of *E. transvena* in competition, and were also consistent with the theoretical predictions for autoparasitoids that parasitize their competitors. Theory did not predict the effect of this interaction on whitefly densities, however. The effect of parasitoid introduction on whitefly densities was different in the two years. In 1997, there was no significant treatment effect on whitefly densities; this was due to high whitefly densities at the time of parasitoid introductions. In 1998, there was a highly significant treatment effect, but the difference was entirely due to differences between the parasitoid treatments and the control; no significant differences were found among the three parasitoid treatments. These results suggest that the competitive interactions between the parasitoids had little effect on whitefly control.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1998

## Searching and Feeding Behavior of *Nephaspis oculatus* and *Delphastus catalinae* (Coleoptera: Coccinellidae), Predators of *Bemisia argentifolii* (Homoptera: Aleyrodidae)

The coccinellids, *Nephaspis oculatus* (Blatchley) and *Delphastus catalinae* (LeConte), are predators of whiteflies (Homoptera: Aleyrodidae) that have shown potential for biological control of *Bemisia argentifolii* Bellows & Perring in greenhouses. The searching and feeding behavior of *N. oculatus* and *D. catalinae* on hibiscus leaves were observed and analyzed in the laboratory to better evaluate their biological control potential. *D. catalinae* larvae maintained the entire body in contact with the substrate while moving whereas *N. oculatus* larvae planted the uropod on the substrate and swept the body in an arc while searching. Even so, the estimated search rate for *D. catalinae* was greater due to faster motion. Larvae and adults of both coccinellid species responded to prey only after making contact using the mouthparts or front legs. Younger larvae took significantly longer time to consume prey than older larvae or adults. Larvae and adults of the smaller *N. oculatus* consumed whiteflies at a significantly slower rate than did the corresponding stage of *D. catalinae*. Comparing stages within species, 1st instar *N. oculatus* spent 53-folds more time consuming an egg than did the adult, and 9-folds more to consume a pupa, compared to 18- and 9-fold differences, respectively for *D. catalinae*. First instar *N. oculatus* preferred 1st instar whitefly nymphs (51%) to eggs (23.6%), or other nymphal instars, and favored pupae least of all. Later larval stages show no significant preferences. *D. catalinae* larvae preferred whitefly eggs, followed by younger nymphs, and finally, pupae. Adults of both coccinellid species showed a strong preference for whitefly eggs (60-77%), followed by nymphs, and finally, pupae. Our results indicate that although feeding preferences of the two beetles are similar, the greater propensity of *N. oculatus* to accept nymphs as well as relatively efficient search behavior and modest food requirements, may favor this species under conditions of low prey density.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** January - December 1998

### Potential Interactions Between Predators and Parasitoids of Sweetpotato Whitefly

A study was initiated to examine the extent to which a general predator would prey on parasitized *Bemisia tabaci*. *Geocoris punctipes* adult females were provided an equal number of parasitized (*Eretmocerus emiratus*) and unparasitized $4^{th}$ instar whiteflies (42 total) in petri dishes and allowed to forage for 24 h at 27EC. Studies were replicated 12 times with early instar parasitoids (displacement of host mycetomes) and 16 times with pupal-stage parasitoids. Preliminary results indicate that *G. punctipes* was about 1.3 times more likely to prey on parasitized compared with unparasitized whiteflies when presented with an equal number of both. This pattern was evident regardless of immature parasitoid age. The slight preference for parasitized whiteflies may be partially due to the fact that parasitized hosts often swell and may be more apparent to foraging predators. Further studies are planned with *Orius tristicolor* and *Collops vittatus*, two other common predator species in central Arizona. These data will aid ongoing efforts to model biological control of *B. tabaci* in cotton, and help to more accurately estimate marginal mortality rates due to parasitism in ongoing life table analyses.

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**Dates Covered by the Report:** January - November 1998

## Prospection and Evaluation of Natural Enemies of *Bemisia tabaci* (Biotype B)

In the last three years, the biotype B of *B. tabaci* has spread to all five regions of Brazil. The northeastern region has suffered more than the others the attack of this insect, because of climate conditions and abundance of host plants. The losses caused by the whitefly is now over US$ 1 billion, attacking crops such as tomatoes, melons, watermelons, cotton, bean and soybean, among others.

A study area was established at Embrapa - Genetic Resources and Biotechnology in order to collect indigenous natural enemies in *B. tabaci* (Biotype B) population. So far, *Signiphora aleyrodis* (Hymenoptera. Signiphoridae) and *Nephaspis gemini* (Coleoptera, Coccinellidae) have been found.

Prospection of *Bemisia* parasitoids was realized in other areas of Brazil. Strains of *Encarsia formosa* were found at the State of São Paulo, the State of Goiás and the Federal District (Brasília). The Brasilia strain of this parasitoid has been evaluated on the silverleaf whitefly populations and the results of parasitism found were: *Lycopersicum esculentum* cv. Salada, 90.75%, *Lycopersicum esculentum* cv. Nemadoro, 84, 25%, *Brassica oleracea* cv. Acephala, 19, 25% and *Nicotiana tabacum* cv. Turkish 45, 65%.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997 - 1998

## Survey and Identification of *Bemisia tabaci* Genn. and its Natural Enemies in India

Survey was conducted on the whitefly in various cassava and sweet potato growing areas, collected and maintained in the net house on cassava, tomato, sweetpotato and tobacco. Two biotypes were identified. Natural enemies include Scymnus sp. (Coccinellidae), Dipteran fly (unidentified), Encarsia flava (Aphelinidae) and pathogenic fungus. The field parasitisation of *E. flava* was found to range from 34 to 36%. E. flava prefers to oviposit on third, fourth and prepupal nymphs. Developmental period from egg to adult ranges from 13 to15 days. Biology, fecundity and longevity were studied. Pathogenicity tests of the fungus showed 50 to 55% pupal mortality. Population dynamics of host-parasitoid-pathogen ratio in the cassava field was in the range of 52:1.2:2 and it was at its peak during May. The ratio between whitefly population present on the lower leaf to middle and to upper leaf in a plant on an average was 1:1.2:1.4.

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**Dates Covered by the Report:** 1997 - 1998

## Biology of Coccinellid Predators of *Bemisia tabaci* Genn.

During the survey three coccinellid predators were observed on *Bemisia tabaci* G. Among them Scymnus sp. is found to be a potential predator of the whitefly, a pest and vector of many viral diseases. The other two species of coccinellid predators were observed to be generalists whereas Scymnus sp. is found to be more of specific to *Bemisia tabaci*. The life history and behaviour of the Scymus sp. was studied in detail. The egg is white and newly emerged grubs are white. In one or two days the grub becomes yellow and subsequently the grubs are being covered with waxy coatings. Then the grubs are found to migrate from one leaf to another. Predation potential ranged from 36-40 %. The egg is transparent and slightly elongated measuring 0.35-0.40 mm in size, laid either singly or in pairs. The developmental duration of egg, larval and pupal stage was in the range of 5-6, 10-11 and 6-7 days. The larvae and the pupae are covered by waxy exudations a characteristic feature of Scymnus sp. It feeds on all stages of whitefly. Adult beetles are more voracious.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** February - May 1998

## Augmentative Biological Control Using Transplants

Early season augmentative releases of *Eretmocerus* spp. (Hymenoptera: Aphelinidae) for control of silverleaf whitefly infesting spring planted melons in Imperial Valley can eliminate the need for late season applications of pyrethroids and other broad spectrum insecticides. This approach can enhance the regional population of highly effective whitefly parasites important to summer and fall field and vegetable crops. It may also promote the longevity of whitefly insecticides by reducing their usage. However, like other augmentative releases of natural enemies, use of *Eretmocerus* is currently expensive, possibly exceeding their short-term economic benefit. We report on a novel approach to enhancing early season field populations of *Eretmocerus* sp. using cantaloupe transplants. Cantaloupe seedlings prior to placement in fields are inoculated with a highly specific whitefly parasite, an *Eretmocerus* population recently imported from the United Arab Emirates. We want to determine whether control of whiteflies in fields receiving transplants inoculated with parasites, or "banker plants," is more effective than in fields receiving conventional hand releases. We hypothesize that parasites on transplants would be a more efficient means of introducing parasites because they would immediately be distributed throughout the entire field and have food readily available to them. Hand released parasites must first search for widely dispersed, low density prey, before parasitizing them. We also want to show that transplants with parasites can be integrated into imidacloprid treated fields at very little additional cost, or at least equal to conventional insecticide costs.

We completed our first field season this last spring. Parasites were released into two commercial farms of cantaloupe in the Imperial Valley. The first was an organic grower, where we compared the effect of banker plants (transplants with parasites) against plots receiving hand-releases of parasites, and a no-release control. Treatments were assigned to 1/3 ac plots using a randomized complete block design with 4 replicates. The second site was a conventional grower who uses imidacloprid (Admire®), and we compared whitefly plant densities in 2 pairs of 1 acre plots with and without the addition of banker plants, respectively.

We succeeded in getting parasites onto banker plants and into fields at both the organic and conventional fields. About 10% of the melon plants in fields receiving banker plants were inoculated with parasites. However, we ended up releasing far fewer parasites using banker plants than we had planned; about 6400 to 7800 parasites per acre at the organic farm and approximately 24,000 per acre at the conventional field. This is much lower than our target of 40,000, the number found to give good control of whiteflies using conventional hand releases. Nevertheless, we measured significant differences in whitefly nymphal populations between the different treatment plots at the organic site. The lowest nymphal populations on the last two sample dates were recorded from the transplant plots, with increasing number in the hand release, and control plots. On 29 May 1998 banker plant plots averaged 0.13 nymphs/cm$^2$ $\pm$ 0.02 (95% CI) followed by hand release plots at 0.18 nymphs/cm$^2$ $\pm$ 0.04, and control plots 0.23 $\pm$ 0.04 nymphs/cm$^2$; and on 9 June 1998 bankers plant plots averaged 0.28 nymphs/cm$^2$ $\pm$ 0.06 followed by hand release plots at 0.41 nymphs/cm$^2$ $\pm$ 0.1, and control plots 0.51 $\pm$ 0.1 nymphs/cm$^2$. We detected few whiteflies at the conventional field receiving an imidacloprid treatment. Parasitism remained extremely low the entire season in both treatments, most likely as a result of a rare host population.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** August 1997 - November 1998

## Fall Releases of Parasites into Citrus

The silverleaf whitefly (*Bemisia argentifolii*) is an increasingly important pest of cotton in the San Joaquin Valley. Field studies suggest that citrus has become an important overwintering site for this whitefly. Cotton has the highest incidence of whitefly infestations in areas of the Valley with a matrix of both citrus and cotton. We report on large scale releases of primarily *Eretmocerus emiratus* and secondarily *E. mundus* and *E. hayati* into three citrus groves. The study has two goals: (1) to determine if exotic parasites released into citrus during the fall will overwinter in this habitat and move into cotton the following spring; and (2) to permanently establish new populations of exotic parasites specific for the silverleaf whitefly.

Three study sites were identified, one each in Fresno, Tulare, and Kern Counties. Sites consisted of citrus and cotton acreage managed by the same owner. Cotton is grown directly adjacent to the citrus, and growers have had a history of silverleaf whitefly problems. They also use the new growth regulators (IGRs) for whitefly control. We began releasing parasites in early September when migrating whitefly nymphs were first recorded from citrus leaves. Over 100,000 parasites were released weekly at each location and a total of 4.05 million were released in 1997 and over 10 million in fall 1998. The dispersal of the released parasites was recorded using sticky cards with identification based on the adult males since they could be readily distinguished from native *Eretmocerus* while on the sticky cards.

The invading adult whitefly populations peaked in early September, 1997 and the egg population shortly thereafter (1998 data has yet to be summarized). Although about the same number of adult whiteflies were caught on sticky cards at the Kern and Tulare County sites, far more eggs and nymphs were recorded at the former. Most of the nymphs recorded from citrus leaves at all three sites were early, not late instars. The Fresno farm never developed substantial whitefly populations in their citrus. The number of whitefly nymphs successfully developing to adults were determined by the presence of an exit hole in the exuviae. At all three sites, the number of nymphal parasites that successfully emerged to adults was only a small fraction of the number of late nymphal instars, less than 1%. The maximum number of whitefly completing development (whitefly exit holes in exuviae) in citrus was recorded from the Kern County Site ($0.016/cm^2$ leaf), with fewer at the other two sites. Preliminary data from a greenhouse study (one replicate) showed that only 19% of eggs matured to adults on citrus in the absence of parasites, with 4% surviving to adults in the presence of parasites. This study was conducted under optimal conditions--humid, warm. These results suggest only a very small fraction of the eggs oviposited by invading whiteflies actually developed to adults.

We began sampling weeds in January for the presence of whiteflies and parasites and that work is ongoing. We also began sampling cotton, but much later than anticipated, around May. Recoveries of exotic parasites this spring from weeds, sticky cards, and in cotton leaves adjacent to citrus shows that released parasites from at least one site moved into and attacked whitefly in adjacent cotton the following spring. We are continuing to sample cotton and citrus to determine which species of released parasites is dominate (80% of our releases were *Eretmocerus emiratus*, and 20% *E. mundus* and *E. hayati*) and to what extent they move into the cotton at all three sites.

**Investigator's Name(s):** Tadeusz J. Poprawski[1] & Matthew A. Ciomperlik[2].

**Affiliation & Location:** [1]Joint Affiliation: Texas Agricultural Exp. Station and USDA-ARS, Beneficial Insects Research Unit, Weslaco, TX; and [2]USDA-APHIS-PPQ Mission Plant Protection Center, Mission, TX.

**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** Summer 1998

## Impact of *Beauveria bassiana* on Natural Populations of Sweetpotato Whitefly Predators

Field applications of *Beauveria bassiana* (the oil-based mycoinsecticide Mycotrol® (ES) at the rate of 5 **x** $10^{13}$ conidia [AI]/ha for control of *Bemisia argentifolii* nymphs were made on 30 June and 7, 20 and 28 July 1998 in soybeans "Vernal' at Mission, TX. Samples of sweetpotato whitefly predators were collected from one 30-m section in the middle of each of 3 replicated plots (treated and untreated plots were 0.135 ha in size) using sweepnets, on 8, 21, 23 and 29 July, and 6 August to determine the impact of the fungus on predator numbers. In addition, predator samples taken from the treated and untreated plots were returned to the laboratory where they were retained to determine which species were affected by the fungus and mortality rates due to mycosis. Additional active predators were collected from the untreated plots. The activity of *B. bassiana* (strain GHA, the AI in the formulated Mycotrol ES) on these predators was assessed using one application rate in a series of 3 laboratory bioassays. The rate applied to the predators (number of conidia per $mm^2$ of the Potter spray tower arena) was 6.25 lower than the field rate. A 0.01% aqueous Tween 80 carrier control was included with the fungal treatment. After treatment, test insects from the field samples retained in the laboratory and those from the bioassays, fed untreated whitefly nymphs ad libitum, were maintained in rearing cages for 10 days, at 25ºC and 50-55% RH under a photophase of 16:8 (L:D) h. Dead insects were removed daily from the cages, surface-sterilized in 0. 13% benzalkonium chloride, rinsed in sterile distilled water and finally plated on 2% agar supplemented with 0.5% gentamicin. The plates were incubated at 25ºC for 48 h and cadavers were scored for overt mycosis (sporulation).

Predator populations were well established within the soybean crop prior to and during *B. bassiana* applications. No significant differences in numbers of predators between the fungus-treated and the untreated plots were found at any given sampling date nor on a seasonal basis **[***t* test on log *(n* + 1) transformation of the data] *(Geocoris punctipes* - all *P*s >0.2*; Scymnus loweii* - all *P*s >0.05; and others *(Collops vittatus, Sinea diadema, Nabis americoferus, Zelus renardii, Notoxus monodon, Chrysoperla rugilabris, Hippodamia convergens, Coleomegilla maculata,* unidentified coccinellids- all *P*s >0.1).

In the retention study, there were generally, but not always, significant differences (chi-square test) in mortality attributable to *B. bassiana* between the predators collected from the fungus-treated plots and the untreated plots. *Geocoris punctipes* - 54. 1% mycosis in the *Beauveria* plots vs. 3.7% in the untreated plots (*P* <0.001) in the 8 July samples, 22.0 vs. 0.6% (21 July; *P <0.001),* 19.3 vs. 0% (29 July; *P* = 0.002); 28.6 vs. 0% (6 August; *P* = *0.*155). Mycosis trends in *S. loweii, N. americoferus,* and several other predator species were similar to the above trends. Moreover, mycosis rates were probably understated because many predators killed by *B. bassiana* most likely fell to the ground and escaped collection.

Laboratory bioassays generally corroborated the retention study data. No control predator died from mycosis. The 10-d Abbott corrected percentages of mortality [mycosis], pooled over the 3 bioassays, in the fungal treatment were: *G. punctipes* - 49.3 [44.4]; *S. loweii* - 21.1 [2.1; and others *(Z. renardii, C vittatus, S. diadema,, N. americoferus, C. rufilabris*, unidentified damsel bugs and coccinelids, and unknown) - 48.4 [13.7] percent.

We conclude that field populations of nontarget beneficial insects are much more adversely affected by applications of *B. bassiana* than previously reported by several authors who drew their conclusions from population estimates made in *situ*.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997 - 1998

## Perennial Plant Refuges for Silverleaf Whitefly Natural Enemy Conservation in Imperial Valley, CA

Numerous perennial plant species have been screened in small plantings to determine their potential usefulness in conserving silverleaf whitefly parasitoids in the Imperial Valley environment, characterized by summer temperatures exceeding 40$^{o}$ C and highly alkaline soils. Several plant species that demonstrated potentially valuable whitefly/parasitoid relationships have been found to be poorly suited for environmental conditions. One of these is *Lavatera thuringiaca* (common name: lavatera). Several desert plant species continue to be of interest. These include, *Tecoma stans* (common name: yellow bells) and *Justicia californica* (common name: chuparosa). In addition, *Alyogyne huegelii* (common name: blue hibiscus) is a recently introduced ornamental from Australia, and often contains populations of heavily parasitized whitefly. This plant has only been under assessment for one year, therefore its tolerance to local soil conditions is not well known. During the past year, two perennial plant strips previously planted with lavatera, chuparosa and rue have been modified by the elimination of lavatera and the addition of yellow bells and a small number of blue hibiscus. In 1999, plants should be large enough to initiate sampling.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997 to 1998

## Establishment of Introduced Parasitoids of the Silverleaf Whitefly in Imperial Valley, CA

Since 1994, a number of exotic *Eretmocerus* and *Encarsia* species/populations have been evaluated in field cages, and released in commercial fields, refuge nursery plots and urban yards. The most promising *Eretmocerus* for this desert region include*: Eretmocerus emiratus* Zolnerowich & Rose, *E. hayati* Z. & R., *E. mundus* Mercet, and *E. sp.* from Ethiopia. To date, one population of *Encarsia* (*E. transvena* (Timberlake) from Pakistan) looks promising.

**Parasitoid population development in un-inoculated refuge nursery plots for 1998:** Four, one-half acre refuge nursery plots were monitored for exotic parasitoid activity. Each plot consisted of okra and basil during the warm season, and collard and sunflower during the cool season. These plots were not inoculated with exotic whitefly parasitoids during 1998 so that populations released in previous years at these sites could be assessed for their ability to overwinter and compete with native species. Overwintering on cole crops was confirmed albeit in low numbers. During the summer, population densities soared on okra, basil and adjacent cotton. Using traits associated with males to distinguish exotic *Eretmocerus* from the native *E. eremicus*, it was determined that by late August there was a greater proportion of exotic *Eretmocerus* (upwards of 80% on okra and cotton) than native *Eretmocerus*. This is particularly noteworthy, because these findings occurred at a time of year when the native *Eretmocerus eremicus* typically reaches high densities. The determination of which exotic *Eretmocerus* species dominated is pending, however, *E. emiratus* and *E. mundus* were common. Within these same plots, *Encarsia transvena* increased to very high densities as well. Based on DNA testing (RAPD-PCR by USDA-APHIS, Mission Biological Control Center, Mission, TX), all *Encarsia transvena* collected in these plots and at all other recovery sites since September of 1997 are those from Pakistan. Prior to the release of *E. transvena* from Pakistan, *E. transvena* from Spain were detected over a one year period (1996 - July of 1997) at several release locations. In contrast to the population from Pakistan, field cage tests and sample data from several locations have indicated that the population from Spain is not capable of rapid population increase during the summer months in Imperial Valley.

**Regional surveys:** During late summer and fall of 1998, exotic *Eretmocerus* and *Encarsia transvena* were collected from numerous ornamental plants in several communities in Imperial Valley, and at a number of conventionally managed cotton fields during early September. Data available to date regarding fall samples of ornamental plants at 15 urban sample sites in three communities indicate that exotic *Eretmocerus* were present in 10 of 15 sites. On average, 25% of the *Eretmocerus* at the 10 locations was exotic. Exotic *Eretmocerus* were detected in two of the eleven cotton field samples. Of these field samples, 6 sites had from 15 to 29 male specimens while 5 sites had from 30 to 66 male specimens. Within the two field sites where exotic *Eretmocerus* were detected, they represented 1-4% of the total *Eretmocerus* population. The locations where exotic *Eretmocerus* were found are remote from all 1998 release locations. In addition, *Encarsia transvena* were detected in one of the cotton fields located no closer than two miles from any known release site.

**Summary:** To date, it has been determined that several newly released parasitoid species have established in the Imperial Valley and are capable of extensive population increase. Survey data for 1998 indicate that these species are becoming widely distributed in urban areas and relatively common in agricultural fields as well.

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1997 - 1998

## Nursery Plots for Establishing Exotic Parasitoids of the Silverleaf Whitefly in Imperial Valley, CA

Field plots of approximately one-half acre are utilized for mass propagation of exotic parasitoid species to facilitate regional establishment. Each site is composed of one quarter acre of okra and one quarter acre of basil planted in March. Second through fourth instar whitefly nymphs are characteristically present on these plantings by early June. During late May through June, each field plot is inoculated with approximately 200,000 of one or a combination of exotic parasitoid species. The number of parasitoids emerging from these plants is very high by late August. Based on sample data consisting of counts of parasitoid pupae per leaf, number of leaves per plant and plants per 1200 row feet (approx. ¼ acre), it was estimated on 28 August 1998 that over one million *Eretmocerus* parasitoids were emerging on a daily basis from the okra plants alone. Furthermore, it was determined that 50% of these were exotic. Because of small leaf size and complex overall plant structure, the estimation of absolute densities of parasitoids on the basil plant component was not done. Typically, whitefly densities on basil are much lower than on okra in Imperial Valley, however, percent parasitism is very high. During 1998, parasitoid densities were sufficient to nearly eliminate whitefly densities, however, whitefly recruitment from adjacent areas continued to support densities of whiteflies in the plots. At one site, approximately 4,000 *Encarsia transvena* on potted collard plants were released. By 28 August there were over 84,000 adult wasps emerging per day on okra.

For two successive years, this method has been very useful for propagating large numbers of exotic parasitoids, from late summer through fall, to facilitate regional establishment. To be successful, it is important to have a very well maintained plot of okra and basil. Weedy plots or otherwise unthrifty plants are of little value.

**Investigator's Name(s):** Alvin M. Simmons[1] & Gloria S. McCutcheon[2].

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**Research & Implementation Area:** Section D: Natural Enemy Ecology and Biological Control.

**Dates Covered by the Report:** 1998

## Attractancy of Crops to a Parasitoid of *Bemisia* and Daily Foraging

The influence of selected horticultural and agronomic plant species on attractiveness for foraging by *Encarsia pergandiella* Howard was determined. Greenhouse tests were conducted with seven diverse crops: cantaloupe, collard, cotton, cowpea, bell pepper, soybean, and tomato. Some of these, such as cantaloupe and cotton, are excellent hosts for *Bemisia argentifolii*, while others, such as cowpea and bell pepper, are substandard whitefly hosts. The tests were conducted on plants free of whitefly nymphs in an open greenhouse colony of indigenous *E. pergandiella*. In addition, greenhouse tests were conducted to determine incidence of daily foraging by this parasitoid. The parasitoid was most attracted to cowpea, followed by cotton. The fewest parasitoids were observed on collard. Attractance was based on the abundance of the parasitoids on the plants following their landing on the leaves. Leaf area was similar among plant types. Specific reasons for variable parasitoid foraging among the plant species may include a combination of factors such as plant semiochemicals, plant color, and plant texture.

The propensity of the parasitoid to forage on the lower leaf surface compared with the upper surface varied among crops (45-90% was on the lower leaf surface) and over time ( 50% was on the lower leaf surface around sunrise while 90% was on the lower surface by mid-day). Overall foraging was low around sunrise and sunset, but peaked near solar noon.

Results from this study have implications on parasitoid conservation, and host plant resistance.

**Research Summary**

## Section D: Natural Enemy Ecology and Biological Control

Compiled by C. H. Pickett and J. R. Hagler

Biological control continues to serve as a major focal point in the development and implementation of a management plan for silverleaf whitefly, *Bemisia argentifolii*. Over the past year significant progress has been made toward introducing, augmenting, and conserving whitefly natural enemies. Moreover, other research areas of the National Silverleaf Whitefly National Research, Action, and Technology Transfer Plan (i.e, Ecology, Chemical Control, Host-Plant Interactions) are giving full consideration to natural enemies in their research programs.

**Classical Biological Control**

Foreign exploration for additional natural enemies of silverleaf whitefly has ceased. Results from field and laboratory studies have narrowed the list of potential candidates for colonization. Classical biological control is now focusing on the regional establishment of five exotic parasitoid species: *Eretmocerus mundus* Mercet, *E. hayati* Z. & R., *E. emiratus* Z. & R., *Eretmocerus* M97076 (Ethiopia), and *Encarsia transvena* (Timberlake) (Pakistan). These parasitoids show signs of establishment in Texas, Arizona, and California. In Texas, where releases have preceded the rest of the country by one to two years, *Eretmocerus mundus* and *E. hayati* comprise an increasing percentage of parasitoids recovered from spring melon fields. Natural enemy refuges consisting of basil, okra, sunflower, and collard have been grown over the last four years at the USDA field station in Brawley (Imperial Valley), California. Each year the proportion of *Eretmocerus mundus*, *E. emiratus* and *Encarsia transvena* recovered from these fields has increased. In 1998, over 80% of the parasitoids recovered near Brawley were exotic which is noteworthy because it was the first year that no additional exotics were released at the field station during the same calendar year. Exotic parasitoids were recovered from 10 of 15 urban sample sites distant from release points in Imperial Valley, California. A survey of cotton fields in the same region in 1998 found exotics in 10 of 21 fields. This indicates that the parasitoids are beginning to spread throughout the region. Summer refuges of basil and okra were grown at two locations in Imperial Valley for mass propagation of exotic parasitoids. While only 200,000 adults were used to inoculate these refuges in early summer, well over one-half million *Eretmocerus* were produced daily in late summer from each of these sites. Citrus orchards infested with migrating whiteflies were used as overwintering refuges in the San Joaquin Valley, California in fall 1997. Several million parasitoids (*Eretmocerus emiratus, E. mundus, and E. hayati*) were released, first into adjacent cotton, then citrus. Parasitoids were found attacking silverleaf whitefly on cotton, citrus, and adjacent weeds, through summer 1998. The same species of *Eretmocerus* were released in large numbers for the first time in cotton growing areas in Mexico just south of El Centro, California. This is a cooperative effort between California and the Mexican government since the silverleaf whitefly is a serious problem on both sides of the border.

Our keynote speaker at this year's meeting spoke on parasitoid impact of whitefly populations and how it can be measured. Classical biological control has been used successfully since the turn of this century to control several species of exotic whiteflies. Impact studies of these programs have been relatively straightforward, comparing whitefly populations in the presence and absence of parasitoids either during releases, or by making pre and post release comparisons. Most of these studies have been done on perennial plants. Silverleaf whitefly attacks an unusually large number of host plants, including many annual crops. The temporal nature of these plants, combined with a broad range of farming practices, including varying pest control tactics, makes it extremely difficult to isolate and measure the sole impact of just the exotic parasitoids. One possible approach may be the use of multivariate statistics. Data collected from a large number of locations, affected by a multitude of factors, can be compared and evaluated. Another possibility is the use of several sentinel plant species that are infested with roughly the same number and stage of whiteflies. These can be placed over a large region to measure the change in parasitoid species composition and number of attacked whiteflies. Advantages include the standardization of plant species, and independence from local whitefly population densities, and pesticide and other farming practices.

**Augmentation**

Three years of field data showed that augmentative releases of exotic *Eretmocerus* in melons could reduce whitefly populations at rates comparable to late season applications of pyrethroids. A novel delivery system is being tested in California and Texas to determine whether the cost of making these releases can be reduced. Transplants of cantaloupe, prior to placement in the field, are inoculated first with silverleaf whitefly, then secondly with exotic *Eretmocerus*. These "banker plants" make up a small proportion of all the planted cantaloupes. The delivery system can reduce rearing costs and increase the efficiency of released parasitoids. Results from the first year's work in California showed that plots receiving banker plants had lower numbers of whitefly nymphs than no-release control plots and the plots where parasitoids were hand released. The banker plant system provided a higher number of release points compared with hand releases, though an equal number of parasitoids were released in both treatments.

*Encarsia formosa* and *E. pergandiella* successfully oviposited on silverleaf whitefly nymphs feeding on an artificial liquid diet. However, *Eretmocerus* failed to do the same. The latter parasitoid oviposits underneath its host, in contrast to *Encarsia* that oviposit directly into its hosts. This artificial diet could be valuable to individuals researching the biology of parasitoids and to the insectary industry. An artificial whitefly diet could greatly reduce the cost of rearing parasitoids by eliminating the need for growing plants. This effort represents the first successful development of whiteflies and their parasitoids on an artificial diet.

Field trials continue to show promise for *Beauveria bassiana* as a pathogen of the silverleaf whitefly. However, laboratory and field studies show that this fungus is toxic to some generalist predators. A variety of whitefly predators collected from *B. bassiana* treated plots had a much higher incidence of mycosis than those collected from untreated plots.

**Conservation**

Progress has been made toward conserving natural enemies. The introduction of "pest-specific" insect growth regulators (IGRs) and the systemic imidacloprid has had a significant impact on whitefly populations in Arizona, and most likely Texas and California. Studies in Arizona showed that IGRs have significantly less negative direct (greater population abundance) and indirect (greater feeding frequency) effects on predators than conventional, broad spectrum insecticides. However, in some instances, predator abundance and feeding behavior were reduced in IGR treated fields when compared to the no-insecticide control fields. Furthermore, a life table analysis on silverleaf whitefly in Arizona cotton showed that predators contribute far more to the total mortality of whitefly eggs and nymphs than previously believed. These studies highlight the importance of using selective insecticides to conserve natural enemy populations.

Decreasing whitefly populations should provide greater potential for the integration of cultural and conservation practices that enhance the role of natural enemies. The life table study also showed that native parasitoids contribute less than 2% to the generational mortality of whiteflies. An increase in parasitism through the introduction of exotics, therefore, may have a large impact on the overall natural biological control of silverleaf whitefly. After several years of screening a number of perennial plant species, some have been selected for testing as a permanent natural enemy refuge. These plants possess some degree of tolerance to drought and very alkaline, salty soils. Additionally, they are attractive to exotic parasitoids, and relatively unattractive to silverleaf whitefly.

**Systematics, Ecology, and Population Dynamics**

A new key was published this year on the exotic *Eretmocerus*. It has helped in the identification of the more commonly released and recovered parasitoids. A new project was initiated in 1998 that will help in the curation and identification of parasitoids recovered from Texas, California and Arizona. The *Encarsia strenua* species group has been revised and *Encarsia transvena* has been renamed as *Encarsia sophia* (Girault).

Studies on the interactions of autoparasitoids and primary parasitoids were conducted using several species of *Eretmocerus* and *Encarsia*. Results show that mixes of *Encarsia,* an autoparasitoid, and *Eretmocerus*, a primary parasitoid, had no negative impact on whitefly control. In fact, in one study, with every increase in the number of parasitoid species, there was a reduction in whitefly numbers. This differs from a simulation model that predicted autoparasitoids would interfere with whitefly control. Differences between these studies and the simulation model may be explained in part by foraging patterns. Preliminary results show that foraging adult female *Encarsia* and *Eretmocerus* may differ in microhabitat preferences. These results have been instructive since populations of *Encarsia sophia* have sustained themselves for at least 2 years in Imperial Valley, and are being considered for release in other regions of the United States.

Another complicating interaction is between generalist predators and parasitic wasps. Earlier studies using the coccinellid *Delphastus pusillus* showed that this beetle avoided feeding on hardened fourth instar whiteflies containing pupating parasitoids. However, recent work in Arizona shows that *Geocoris* is more likely to attack the more apparent, parasitized whiteflies.

Tritrophic studies on both *Encarsia* and *Eretmocerus* highlight the complexity in the interactions among plant, host, and parasitoid. Parasitoids showed different preferences for plants, in the absence of whiteflies. Oviposition rates of parasitoids varied depending on the host whitefly (*Bemisia* vs. *Trialeurode*s) and host plant on which foraging was monitored. Sex ratios of parasitoid progeny were also affected by host plant and whitefly species.

A new marking method using a protein was tested on whitefly parasitoids. This simplified marking tool is superior to conventional markers and can aid in studies on the movement of parasitoids between various crops and between non-crop and crop vegetation. In Arizona, mass-reared *E. mundus* were released in cotton and cantaloupe in order to determine its within crop and between crop dispersal patterns. Data indicate that *E. mundus* only moved a few meters from their release sites, regardless of the crop in which they were released. Virtually no intercrop movement was observed. Dispersal patterns of parasitoids are of interest to those making augmentative releases and natural enemy refuges to enhance the activity of indigenous parasitoids.

**Technology Transfer**

Progress has been made in passing new technology to clients working in agriculture. Cultures of exotic parasitoids, imported into the United States and evaluated both in the laboratory and field, have been transferred to Koppert, a large European commercial insectary. A new artificial diet for rearing silverleaf whitefly has been tested. It may lead to reduced costs in mass rearing natural enemies. The protocol for this diet is also being passed to other researchers. Advances in rearing technology have greatly increased the output of parasitoids being massed reared and released throughout the southwest and Texas. A new key on exotic *Eretmocerus* will aid those identifying parasitoids recovered from field samples, as well as those who are rearing them for commercial purposes. Advances have been made in developing a simpler, more durable insect marking technique. The technology behind this protein marking technique has been passed to other, large-scale research programs (i.e., sterile insect release programs) throughout the world. Such tools are needed to advance our understanding movement, either within or between different types of vegetation. Emerging technologies include “banker plants,” that can be used to deliver parasitoids into cantaloupes more efficiently than traditional methods.

**Table D. Natural Enemy Ecology and Biocontrol.**

| Research Approaches[a] | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Natural control and conservation:** | | | | |
| **Develop natural enemy conservation practices to reduce mortality to indigenous and introduced natural enemies.** | Conduct life table analyses of indigenous and introduced natural enemies to identify key mortality factors of natural enemy populations. | X | | New insect growth regulators tested well under field conditions, and reduced loss of natural enemies. A Life Table analysis was conducted on natural enemies in cotton. |
| **Evaluate potential of alternate plants to act as in-field refuges or insectaries for natural enemies.** | Identify potential plants for natural enemy population development and assess risks of these plants to foster additional pest problems. | X | | Combinations of annuals and some perennials show promise as within field natural enemy refugia. They are attractive to parasites but support low numbers of whiteflies. Annuals served as outdoor insectaries when releasing exotic parasitoids. |
| **Assess cues used by natural enemies to locate whitefly and to identify potential methods for enhancing natural enemy activity.** | Conduct laboratory tests to identify cues used by natural enemies to locate and attack whitefly. | | X | Some research has been initiated but was not reported at this meeting. |
| **Augmentation of natural enemies:** | | | | |
| **Develop natural enemy mass-rearing systems.** | Identify natural enemies with the highest potential for controlling whitefly in key cropping systems. | X | | Diets are being developed for generalist predators. Improvements have been made in rearing parasitoids, increasing rearing efficiency. Field studies have identified promising candidates for augmentative releases |
| **Develop release technologies to maximize the effectiveness of mass-reared natural enemies in the field.** | Identify natural enemies with the highest potential for controlling whitefly in key cropping systems and that may be economically mass produced. | X | | A novel "Banker Plant" field release strategy shows promise for increasing efficacy of releases. Releases of *Eretmocerus* into greenhouses controlled *Bemisia* attacking poinsettias when done at low pest densities. |

**Table D. Natural Enemy Ecology and Biocontrol. (continued)**

| Research Approaches[a] | Year 1 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Evaluate augmentative parasitoid, predator, or pathogen releases.** | Initiate studies on natural enemy augmentation with identified high potential natural enemies. | X | | Augmentative releases of parasitoids controlled *Bemisia* in large demonstration fields. These releases can be integrated with conventional pest management practices |
| **Importation biological control:** | | | | |
| **Evaluate the ability of exotic natural enemies to suppress whitefly populations under field conditions.** | Identify sites suitable for the release and subsequent evaluation of each candidate natural enemy. Conduct inoculative releases of natural enemies. | X | | Combinations of annual plants that make excellent insectaries and can be farmed under local climatic conditions have been identified. Homeowners are being recruited to care for plants used for making releases |
| **Systematics, ecology, and population dynamics of natural enemies:**[b] | | | | |
| **Clarify sytematics of predators, parasitoids and pathogens.** | Conduct taxonomic studies of species within targeted releases sites. Verify taxonomic purity of mass-reared natural enemies. Complete taxonomic work on poorly characterized but important groups. Assist in determining most suitable natural enemies for release through biogeographical analysis. | X | | Taxonomic studies have been completed on the exotic *Eretmocerus* and a key to their identification is in press. PCR techniques have been developed to identify the purity of cultures and aid in identification of recovered parasites. |
| **Determine *Bemisia*- natural enemy-host plant (Tritrophic) interactions.** | Initiate studies to identify mechanisms involved in *Bemisia*- and natural enemy plant attraction. | X | | Controlled laboratory studies showed that *Bemisia* and aphelind oviposition rates varied depending on host plant. |
| **Identify the attributes of natural enemy biology and population level interactions to explain biological control successes and failures.** | Assess the value of the *Bemisia* biological control research to evaluate key issues to the science of biological control. | X | | The role of autoparasitism in native populations of *Encarsia* and its impact on native *Eretmocerus* has been evaluated. Results from one study show no adverse affect of *Encarsia* on overall parasitism of SLWF |

[a] See Table C for complementary research.
[b] See Table A for complementary research.

**Table D. Natural Enemy Ecology and Biological control.**

| Research Approaches[a] | Year 2 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Natural control and conservation:** | | | | |
| **Develop natural enemy conservation practices to reduce mortality to indigenous and introduced natural enemies.** | Evaluate predator gut contents. Conduct life table analysis. | X | | Role of predators in cotton identified; importance of narrow spectrum insecticides highlighted. |
| **Evaluate potential of alternate plants to act as in-field refuges or insectaries for natural enemies.** | Determine refugia plant phenology in relation to cultivated crop phenology. | X | | Perennial plants capable of growing in Imperial Valley identified, selected for a pilot project at a commercial organic farm. |
| **Assess cues used by natural enemies to locate whitefly and to identify potential methods for enhancing natural enemy activity.** | Determine potential methods for manipulating cues as part of a whitefly management program. | | X | No work reported. |
| **Augmentation of natural enemies:** | | | | |
| **Develop natural enemy mass-rearing systems.** | Determine nutritional, physiological, and ecological requirements for mass-rearing. | X | | Whitefly, parasitized by *Encarsia*, were grown on an artificial diet long enough for parasitoids to emerge as adults. First such report. Potential for research and commercial rearing. |
| **Develop release technologies to maximize the effectiveness of mass-reared natural enemies in the field.** | Evaluate the fate of natural enemy life stages under field conditions to identify the appropriate developmental stage to be released. | X | | First year results show banker plants may prove more efficacious than releases of parasitoids by hand. Two species of coccinellids evaluated, compared for greenhouse use. |
| **Evaluate augmentative parasitoid, predator, or pathogen releases.** | Conduct releases on selected crop systems at various rates of release. | X | | Impact of *Beauveria bassiana* on generalist predators determined. Parasitoid dispersal was determined using new protein marking technique |

**Table D. Natural Enemy Ecology and Biological Control. (continued)**

| Research Approaches[a] | Year 2 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Importation biological control:** | | | | |
| **Evaluate the ability of exotic natural enemies to suppress whitefly populations under field conditions.** | Evaluate establishment of exotic natural enemies within target release area. Determine if additional releases are necessary. | X | | Several new exotics have persisted over several years and are multiplying and spreading in Texas and California. |
| **Systematics, ecology, and population dynamics of natural enemies:**[b] | | | | |
| **Clarify sytematics of predators, parasitoids and pathogens.** | Provide taxonomic support for importation and mass-rearing programs. Publish keys to assist in species identifications. | X | | Key on exotic *Eretmocerus* published. Program developed for curating, cataloging recovered parasitoids. |
| **Determine *Bemisia*- natural enemy-host plant (Tritrophic) interactions.** | Study plant characteristics mediating whitefly and natural enemy population densities. | X | | Parasitoid foraging, oviposition varied in response to different plants (crops) and host whitefly. Plants varied in color, architecture, and semiochemicals. |
| **Identify the attributes of natural enemy biology and population level interactions to explain biological control successes and failures.** | In conjunction with field evaluations, validate predictions made by behavioral and population models important to biological control. | X | | No interference competition measured, with respect to whitefly control, when mixing primary parasitoids and autoparasitoids. |

[a] See Table C for complementary research.

[b] See Table A for complementary research.

## Reports of Research Progress

### Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions

Co-Chairs: Alvin Simmons and Greg Walker

**Investigator's Name(s):** J. L. Bi, G. R. Ballmer, & N. C. Toscano.

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**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** 1998

### Effect of Nitrogen Fertility on Cotton-Whitefly Interactions

The impact of nitrogen fertility on silverleaf whitefly (*Bemisia argentifolii* Bellows & Perring) population dynamics and honeydew production, and the related biochemical and physiological mechanisms involved, were investigated in cotton (*Gossypium hirsutum* L., c.v. Acala) in California. Five nitrogen levels were evaluated using urea in a randomized complete block design with five replicates. Treatments consisted of soil applications of 0, 100, 150, and 200 lbs nitrogen per acre, and a soil application of 100 lbs nitrogen together with a foliar application of 10 gal of low-biuret urea per acre. In comparison with the control treatment (0 lbs nitrogen per acre), applied nitrogen to cotton plants increased densities of silverleaf whiteflies per fifth node leaf throughout the season. Within the nitrogen treatments, the higher rates of application (150 and 200 lbs nitrogen per acre) resulted in higher densities of whiteflies. Higher nitrogen treatments also resulted in higher densities of honeydew drops produced by the whiteflies. The impact of nitrogen fertility on whitefly densities and honeydew drop densities was more apparent in late season. Also, the nitrogen treatments generally enhanced cotton foliar photosynthetic rates and altered concentrations of several soluble carbohydrates such as glucose, fructose, and sucrose in cotton petiole. These results suggest that nitrogen fertility is an important determining factor controlling whitefly population dynamics and honeydew production. The precise biochemical and physiological mechanisms involved are currently being evaluated and will be discussed.

**Investigator's Name(s):** Nathalie Boissot & Claudie Pavis.

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**Research & Implementation Area:** Section E: Host-Plants Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** 1998

## Resistance Against *Bemisia tabaci* B Biotype in Melon

In Guadeloupe and Martinique (French West Indies), *Bemisia tabaci* outbreaks have occurred since 1990, especially on cucurbits. The whitefly was described as *Bemisia tabaci* B biotype (Sauvion et al., submitted). We started to study the host plant resistance in *Cucumis melo* in 1997.

In 1997/98, 68 genotypes (from the germplasm collection of INRA-Avignon, France) were tested under natural infestation (66 *Cucumis melo*, 1 *Benicase cerifera*, 1 *metuliferus*). Sixteen plants per genotype (4 plants x 4 plots were observed: 1) 2 and 4 weeks after planting (WAP), the adults were counted under 2 leaves/plant. 2) 4,5,6 and 7 WAP, the eggs were counted under 2.22 $cm^2$ leaf discs/plant. 3) 6,7,8, and 9 WAP, the larvae were counted under 2.2 $cm^2$ leaf discs/plant, the discs were sampled on the same leaves as for the eggs, at 4,5,6 and 7 WAP, respectively.

The adult counts allowed to estimate the importance of the natural infestation. Resistance parameters are evaluated from the egg counts (antixenosis for egg-laying) and from the relationship between the number of eggs and the number of larvae (an indicator of antibiosis). As infestation level can be variable, VÈdrantais was present in each trial. Some genotypes as OuzbËque 1, Top Mark, Iran B or B66-5 were more susceptible than VÈdrantais. Six genotypes were tested in 1997 and 1998: 90625, Kanro Makuva, PI 161375, PI 414723, Gaizabadi Phoont and HSD 200 and scored better than VÈdrantais. Among the 68 genotypes tested,, 26 were described resistant to *Aphis gossypii*. The variability in the scoring of those genotypes (better or worst than VÈdrantais) showed that the resistance against *Bemisia tabaci* B and *Aphis gossypii* were independent. From this screening, it appears that 10 genotypes have possibly partial resistance against *Bemisia tabaci* B (antixenosis and antibiosis).

The second step of the study was to develop a bioassay in order to quantify resistance to egg-laying and to larval development. This was made using synchronized mass-rearing. These preliminary tests allowed to determine the following optimal conditions for bioassaying. Adults are collected in the rearing cage during the emergence peak. Females are separated from males under binocular microscope at 10EC, after been placed 2½ minutes at 12EC. Thirty females are then allowed to lay eggs during 6 hours, on the second leaf of a 3-leaf plant. Plants are grown in climatic chamber (T=27 ± 1EC, HR=85 ± 10%). After 5 and 10 days, respectively, eggs and larvae are counted. Adult emergences are daily recorded counting empty puparial exuviae. The emergence curve follows a Gompertz distribution, where the m parameter indicates the mean larval development duration. The germplasm evaluation is now in progress, using this standardized bioassay.

Sauvion, N., C. Pavis, A. Huc, M. Rousseau, and N. et Boissot. Caractérisation de *Bemisia tabaci* biotype B (Hempitera: Aleyrodidae) en Guadeloupe. *Ann Soc. Entomol Fr*.

**Investigator's Name(s):** Nathalie Boissot, Denis Lafortune, Georges Ano, Claudie Pavis, & Nicolas Sauvion.

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**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** January 1, 1996 - August 31, 1998

## Resistance Against Geminivirus and *Bemisia tabaci* B in Tomato and Melon

In Guadeloupe and Martinique (French West Indies), *Bemisia tabaci* outbreaks have occurred since 1990, especially on Cucurbits with its concomitant geminivirus epidemics on tomato crops. The whitefly was described as *Bemisia tabaci* B biotype and the geminivirus as the PYMV (see Urbino *et al*., in this progress report).

Facing this situation, INRA developed two programs on host plant resistance:

- Tomato resistance against geminivirus: first, field screening under natural infestation allowed to identify genitors of resistance to PYMV. Eighty plants per genotype were observed in 1996/97/98 (20 plants x 4 plots). Symptoms were observed every week and rated through a 1 to 5 scale. More than 80 genotypes (families, F1 hybrids and inbred lines) were tested. Those genotypes mainly came from populations bred for resistance against TYLCV by Henri Latterot (INRA Avignon, France). The rating varied from 2 to 5, indicating that partial resistance against PYMV is present in the tested genotypes. As *Ralstonia solanacearum* is a major constraint in the West Indies, the second step of the program was to associate the complete resistance against *R. Solanacearum* (from the inbred line 'Caraïbo') to the partial resistance to PYMV observed in different sources. Crosses were made and the F3 families were tested for resistance against the two pathogens in different trials. Inbred lines are under way to be obtained from the best families.
- Melon resistance against *Bemisia tabaci* B biotype: In 1997/98, 70 genotypes (from the germplasm collection of INRA-Avignon, France) were tested under natural infestation. Sixteen plants/genotype (4 plants x 4 plots) were observed :
    - 2 and 4 weeks after planting (WAP), the adults were counted under 2 leaves/plant.
    - 4, 5, 6 and 7 WAP, the eggs were counted under 2.22 $cm^2$ leaf discs/plant.
    - 6, 7, 8 and 9 WAP, the larvae were counted under 2.22 $cm^2$ leaf discs/plant, the discs were sampled on the same leaves as for the eggs, at 4, 5, 6 and 7 WAP respectively.

The adults counts allowed to estimate the importance of the natural infestation. Resistance parameters were evaluated from the egg counts (antixenosis for egg-laying) and from the relationship between the number of eggs and the number of larvae (an indicator of antibiosis). From this screening, it appears that 10 genotypes have possibly partial resistance against *Bemisia tabaci* B (antixenosis and antibiosis). We are now developing bioassays to analyze and quantify the resistance.

**Investigator's Name(s):** James S. Buckner[1], Thomas P. Freeman[2], C.C. Chu[3], Dennis R. Nelson[1], & Thomas J. Henneberry[3].

**Affiliation & Location:** [1]USDA-ARS, Biosciences Research Lab., Fargo, ND; [2]Electron Microscopy Center, Plant Pathology Department, North Dakota State University, Fargo, ND; [3]USDA-ARS, Western Cotton Research Lab., Phoenix, AZ.

**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** 1998

## Whitefly Egg Pedicel Morphology and Penetration Characteristics

Whitefly eggs are generally elongate-oval and the basal end has a pedicel or stalk of varying length by which the female attaches the egg to a plant leaf. *B. argentifolii* females insert the pedicel into a slit made in the leaf by the ovipositor and secrete a glue-like substance around the pedicel. In addition to anchoring the egg to the leaf surface, the indicated function of the pedicel is to serve as a conduit for absorbing water to protect the egg from dehydration. Using established methods for leaf tissue fixation, embedment, sectioning and staining, the penetration characteristics of *B. argentifolii* eggs inserted into cotton leaves were observed by both light and transmission electron microscopy. Scanning electron microscopy (SEM) was used to observe and characterize oviposited eggs removed from cotton leaves and artificial membranes. The morphology of the pedicel of eggs removed from leaves and membranes was compared to the pedicel of eggs removed from the ovaries of gravid *B. argentifolii* females.

For cotton leaves, the pedicels *B. argentifolii* eggs were most often inserted into abaxial epidermal cells. We observed that the distal end of most pedicels was curved within the plant epidermal cells. A glue-like substance was observed to envelop the base of the pedicel, but not the tip region. This glue-like collar was also observed on the pedicel of eggs removed from artificial membranes. These findings imply that the female secretes the glue-like substance at the time of egg insertion.

SEM observations of eggs removed from ovaries indicate that the pedicels have two distinct morphological areas. The proximal portion of the pedicel appears as an extension of the smooth-surfaced egg chorion. The distal end of the pedicel appears to be covered with an array of tangled-like fibers. Longitudinal sections of oviposited *B. argentifolii* eggs show the chorion layer ending along the upper portion of the pedicel. This fibrous appearance at the distal end of the pedicel supports the suggestions and evidence for water uptake into the egg.

**Investigator's Name(s):** [1]C. C. Chu, [1]A. C. Cohen, [2]E. T. Natwick, [3]G. S. Simmons, & [1]T. J. Henneberry.

**Affiliation & Location:** [1]USDA-ARS, Western Cotton Research Laboratory, Phoenix, AZ, [2]University of California Imperial County Cooperative Research and Extension Center, Holtville, CA, and [3]USDA-APHIS PPQ WR, Brawley, CA.

**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** 1996

## Silverleaf Whitefly Colonization and Leaf Morphology Relationships in Upland Cotton Cultivars

Studies were conducted at Holtville, CA in 1996 to investigate the relationships between upland, *Gossypium hirsutum* L., leaf morphology and whitefly population densities. There were eight United States Deltapine (DPL) cultivars: DPL 20, 50, 90, 5415, 5432, 5461, 9050, and 9057 and six Australian cotton cultivars and breeding lines, CS 50, Siokra 1-4/649, Siokra L23, Siokra V-15, 87031-126, and 89013-114. Results showed that Australia okra-leaf cultivars and lines were colonized with fewer whitefly adults, eggs and nymphs compared to Australia and United States normal-leaf cultivars. The distances from underleaf surfaces of cotton leaves to the centers of nearest minor vascular bundles was negatively correlated with whitefly adult, egg and nymphal densities on leaves for all genotypes with exception of the Australian breeding line 89013-114. Our results suggest that the okra-leaf character and the distance from underleaf surfaces to the center of nearest minor vascular bundles of cotton leaves are genetic traits that have potential for breeding whitefly resistant upland cotton cultivars.

**Investigator's Name(s):** [1]C. C. Chu, [2]T. P. Freeman, [3]J. S. Buckner, [4]E. T. Natwick, [3]D. R. Nelson, & [1]T. J. Henneberry.

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**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** 1996 - 1998

## Silverleaf Whitefly Oviposition on Upland Cotton Cultivars

**Silverleaf Densities and Egg Distribution on Selected Upland Cotton Cultivars.** Oviposition as a critical life stage of silverleaf whitefly reproduction has been used an indicator of adult behavior, host plant preferences, host plant resistance, leaf age preference, and effectiveness of insecticide treatments. It has been reported to be affected by leaf trichomes, leaf age and leaf position on the stems, leaf moisture and temperature, and nutritional condition of leaves. After landing on cotton leaves, silverleaf whitefly adult females immediately begin stylet probing activities on leaf surfaces. Eggs laying may occur before stylets penetrate into phloem tissue. Whitefly egg distributions are aggregated and in cotton, eggs are generally laid on or within ca. 30 µm of vascular bundle-associated elongated epidermal cells. We report here on silverleaf whitefly adult, nymph and egg densities on cotton leaves, an examination of the egg distribution and mechanisms of ovipositional site selections in relation to underleaf surface features of five upland cotton cultivars: Deltapine (DPL) 50, 5415 and 5432, Fibermax 832 and Siokra L23. Deltapine 5415 and 5432 had the highest and Siokra L23 the lowest numbers of eggs and nymphs. Siokra L-23 also had the lowest number of adults compared to the other four cultivars. On the average, 72% of the eggs were laid on leaf surfaces between veins and 25 % were laid on veins that were # 4 or fewer cells wide. Few eggs were found on veins that were 5 or more cells wide. No eggs were inserted into leaf stomata.

**Silverleaf Whitefly Egg Penetration in Upland Cotton Leaves.** Silver leaf whitefly adults laid eggs almost exclusively on the lower surface of cotton leaves while the adults were resting or feeding. Eggs are oval shaped about 105 µm long and 60 µm in diameter. Eggs were laid randomly depending on the locations where adults were feeding or resting. Adults insert their ovipositors into lower epidermal cells, lay one egg at a time with the pedicel anchored directly into or between cells. The egg pedicel may penetrate completely through the epidermal cell into a mesophyll cell or the intercellular space between mesophyll cells. The pedicel of all eggs were surrounded by a ‘cement’ which appeared to anchor the eggs into the leaf tissue. The composition of the ‘cement’ is unknown.

**Investigator's Name(s):** [1]Thomas P. Freeman, [2]C. C. Chu, [3]James S. Buckner, [3]Dennis R. Nelson, & [2]Thomas J. Henneberry.

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**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** 1998

## Variations in Cotton Leaf Morphology Related to Whitefly Feeding

Whiteflies (*Bemisia argentifolii*) are known to prefer some cotton varieties over others. There has been considerable speculation as to why this is the case. Differences in leaf morphology between varieties have frequently been considered to be a major factor. In an effort to test this hypothesis, we examined two varieties of cotton grown in Arizona during the 1998 growing season. The seasonal means of adults, eggs and nymphs on cotton leaves for the period 22 July1998 to 23 September, 1998 were: ST474 19.36 adults per leaf, 14.96 eggs per square centimeter leaf disk, 4.12 nymphs per square centimeter leaf disk compared to DPL5415 with 7.59 adults per leaf, 0.86 eggs per square centimeter leaf disk, and 0.36 nymphs per square centimeter leaf disk. The morphological-anatomical characteristics of seven leaves along the main stem of three plants of each variety were examined. Leaf 1, 3, 5, 7, 10, 15 and 20 were selected. Leaf 1 is the youngest leaf at the apex of the plant with leaves 3-20 located at successively lower nodes. The average size of leaf 1 at the time of collection was approximately 11 square centimeters. The parameters examined included; total leaf area, areole area, number of terminal vein endings per unit leaf area, number of mucilage ducts per unit leaf area, leaf thickness, distance from lower epidermis to phloem tissue, and the number of trichomes per unit leaf area.

There were differences recorded in leaf area between the two varieties but these differences were not consistent in leaves of different ages and in all replicates. Leaf 20 was always smaller in area and thinner than leaves 10 or 15.

Cotton leaf thickness and phloem depth are frequently considered to be the major morphological characteristics responsible for varietal selection by whiteflies. The measured difference in these characteristics was not very great between ST474 and DPL5415, and probably cannot be used to explain the noted preferences of one variety over the other. There were, however, very significant differences between young and old leaves in each variety which no doubt does explain why younger leaves are preferred. In leaf 1 of both varieties the phloem was located approximately 50 microns from the lower epidermis. Normal leaf expansion results in the phloem being much deeper, as great at 130 microns in leaf 15. This may be a depth too great to be reached by either adults or nymphs.

Portions of each leaf were cleared to determine the vascular pattern. It was possible using this technique to determine the average areole area as well as the number of terminal vein endings per unit leaf area. Here again there were few differences between the varieties but significant differences between leaves of different ages. The areole area was much smaller in younger leaves which means that both whitefly adults and nymphs can reach phloem tissue from almost any position on the leaf surface. This may account for the preference of young leaves over older more mature leaves on the same plant.

The number of mucilage glands per unit leaf area did not appear to differ between ST474 and DPL5415 and therefore, probably does not play a major role in variety selection by the whiteflies. The differences detected between younger and more mature leaves was related to normal leaf expansion.

The number of elongated trichomes was significantly different between the two cotton varieties and may be related to why whiteflies prefer ST474 to DPL5415.

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**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** 1996

## Behavioral and Developmental Effects of Trichome Defenses in *Datura wrightii* on *Bemisia*

Plant morphology can have a strong impact on whitefly population dynamics, especially in the case of leaf surface characteristics that physically prevent feeding or that cause mortality directly. In this study, three lines of a common weed species of the southwestern US, Jimson weed (*Datura wrightii*) were investigated for their ability to prevent colonization by *Bemisia tabaci* whiteflies. This weed species acts as an important non-crop reservoir for whiteflies, and different lines *of D. wrightii* were collected from the wild that exhibit marked variation in the form and extent of their leaf-based defenses. The three lines differed in the density of trichomes, and in the extent to which these trichomes were glandular. This variation provided a situation in which the importance of the density and glandularity of trichome defenses could be critically evaluated.

Observations of the behavior of whiteflies encountering the surfaces of young, medium and mature leaves were performed using a microscope system with data recorded onto a computer-based event recorder. These experiments demonstrated the importance of glandular hairs in preventing egg laying by trapping adult female whiteflies soon after leaf contact. In choice tests, adult whiteflies were released inside cages containing leaves of all three lines of *D. wrightii*. The number of insects found alive on leaves in this experiment over an 8 h observation period was significantly affected by both the density of trichomes and the presence of trichome glands. The greatest impact on whitefly survival was found on the glandular line, wherein the number of dead insects steadily increased over time. Adult whiteflies that were flying within the cages were trapped by the defenses of this line and did not escape. In addition, observations of adult eclosion from nymphs that has survived below the trichome glands, showed that these insects were instantly trapped during their movement from the site of emergence.

These data provide further strong evidence for the potential of trichome-based defenses for whitefly mitigation in agricultural systems. Selective manipulation of the weed population around crop plants may be a practical method for suppression of whitefly immigration, in contrast to the general recommendations for weed removal.

**Investigator's Name(s):** D. Michael Jackson, Mark W. Farnham, & Alvin M. Simmons.

**Affiliation & Location:** USDA-ARS, U. S. Vegetable Laboratory, Charleston, SC.

**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** 1997 - 1998

## Effects of Interplanting of Collard Phenotypes on Resistance to Whiteflies

We previously reported that in small-plot experiments, glossy collard phenotypes averaged significantly fewer whitefly adults and nymphs than did standard, nonglossy phenotypes. Glossy phenotypes have reduced concentrations of leaf waxes, which causes their glossy or shiny appearance. One collard cultivar of particular interest is 'Green Glaze', which segregates into glossy (resistant) and nonglossy (susceptible) phenotypes. We also previously reported that an unrelated, nonglossy cultivar, 'Blue Max', had significantly fewer whitefly adults, nymphs, and eggs than other nonglossy cultivars. However, 'Blue Max' is not as resistant as any glossy collard, and its mechanism of resistance is not known.

In 1997 and 1998, we evaluated the effects of an interplanting pattern of resistant and susceptible collard on whitefly infestations and on the occurrence of natural parasitoid species. The two phenotypes of 'Greenglaze' (glossy and nonglossy) were evaluated for infestations of *Bemisia argentifolii* in mixed and solid plantings. Over a two-year period, there were no differences in the abundance of whiteflies on the glossy phenotype when it was planted in solid 20-plant plots or when it was alternated (every other plant) with the nonglossy (susceptible) phenotype. However, for some of the data sets, the numbers of whiteflies on the nonglossy phenotype in mixed plots were reduced. Overall, 'Greenglaze'-Nonglossy/Solid Planting had 52% of the whitefly adults counted, 'Greenglaze'-Nonglossy/Mixed Planting had 38%, 'Greenglaze'-Glossy/Solid Planting had 4%, and 'Greenglaze'-Glossy/Mixed Planting had 6%. In 1998, yellow sticky card traps were placed in the field during the peak whitefly period, and native parasitoids were monitored. Significantly higher numbers of whitefly parasitoids were collected from sticky cards in the solid plantings of 'Greenglaze'-Nonglossy, and very few parasitoids were found in the solid plantings of 'Greenglaze'-Glossy. Counts of parasitoids on sticky cards in the mixed plots were intermediate.

A similarly designed experiment was setup in 1998 with plants of the resistant 'Blue Max' and the susceptible 'Morris Heading' collard cultivars. Again, there was no difference in the resistance of 'Blue Max' in either planting scheme, but late in the season when whitefly populations were very large, the number of whiteflies on the susceptible cultivar was reduced in the mixed plots. Overall, 'Morris Heading'/Solid Planting had 46% of the whitefly adults, 'Morris Heading'/Mixed Planting had 34%, 'Blue Max'/Solid Planting had 10%, and 'Blue Max'/Mixed Planting had 10%. These data show that planting pattern is relatively unimportant in the deployment of these sources of host plant resistance.

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**Research & Implementation Area:** Section E: Host Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** March - December 1998

## Cotton Leaf Crumple Geminivirus Disease Resistance In Upland Cotton

Nine upland cotton, *Gossypium hirsutum* L., cultivars or experimental breeding-lines were evaluated in the field for resistance to the silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, transmitted cotton leaf crumple disease caused by cotton leaf crumple geminivirus (CLCV) in Imperial Valley, CA in 1998. The cultivars were Texas 121 and Stoneville 474 and the breeding-lines with Cedix parentage were C118-2-93, C952103, C95383, C953109, C95483, C95271, and C95387. Disease symptom ratings for CLCV (1= no symptoms, 2= mild leaf crumpling, 3= moderate leaf crumpling, and 4= severe leaf crumpling) were taken on 21, 28, and 31 August and on 4 September. Leaf and petiole samples from each plot were sent to the Plant Pathology Department at UC Davis to confirm the presence of CLCV by squash and dot blot hybridization with a general DNA probe, which detects the presence of whitefly transmitted geminiviruses and DNA sequencing of a polymerase chain reaction amplified fragment from an infected plant confirmed that the geminivirus was CLCV.

Results showed that there were differences in whitefly infestation levels and virus disease symptoms among the cotton entries in this study. The experimental cotton breeding-line C95387 had a lower CLCV disease symptom rating (1.1) (p # 0.05, SNK) than other entries in the study and no CLCV was detected through by squash and dot blot hybridization with a general DNA probe. The experimental cotton breeding-lines C95383 and C95483 had a lower CLCV disease symptom rating (2.2 and 2.1 respectively) (p # 0.05, SNK) than other entries in the study except C95387. The cotton cultivar Stoneville 474 had a higher CLCV disease symptom rating (3.7) (p # 0.05, SNK) than other entries in the study.

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**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** March - December 1998

## Silverleaf Whitefly Infestation Levels on Normal Leaf and Okra-Leaf Upland Cotton Cultivars

Sixteen upland cotton, *Gossypium hirsutum* L., cultivars and experimental breeding-lines were evaluated in the field for susceptibility to silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, sown at the UC Desert Research & Extension Center, Imperial Valley, CA, into plots of a randomized complete block design experiment replicated four times, and irrigated 25 March, 1998. The normal leaf cultivars were DP 20, DP 50, DP 90, DP 5415, DP 5432, DP 5461, DP 9775, DP5557, Stoneville 474, and Texas 121, and the okra-leaf cultivars and breeding-lines were Siokra L23, FiberMax 832, FiberMax 819, FiberMax 975, CSIRO 91212-265, and CSIRO 89230-244-1028. Individual plots measured 14 m in length with 4-beds on 1 m centers. No insecticides were applied to the cotton plots. Silverleaf whitefly adults were sampled from ten plants at random in each plot via the leaf turn method using the 5th main stem leaf from the terminal on 10, 17 June, 7, 14, 21, 28 July, 4 & 12 August, 1998. Silverleaf whitefly eggs and nymphs were counted on 1.54 $cm^2$ leaf disks of from ten 5th position leaves down from the terminal extracted from randomly selected plants in each plot on 10, 17 June, 7, 15, 21, 28 July, 4 & 12 August, 1998. Seed cotton was hand picked from 0.002 acre per plot and yield data were recorded on 27 August, 1998. The okra-leaf entries as a group had fewer silverleaf whitefly adults, eggs and nymphs than the normal leaf cotton entries. Siokra L23 had the lowest numbers of silverleaf whitefly adults, eggs and nymphs among the okra-leaf entries. There were no differences in seed cotton yield among the entries, p # 0.05, SNK.

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**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** 1998

## Plant-Insect Interactions: the Defense Reaction of Tomato to Whitefly Feeding

Silverleaf whiteflies have devastated agricultural crops across the southern United States and throughout the world. This phloem-feeding insect not only transmit many plant viruses but also causes several developmental disorder. These disorders range from irregular ripening of tomatoes to silvering of squash leaves. Many of these disorders lead to unmarketable products. Although plant-insect interactions are a major part of the study of plant defense mechanisms, little is known about how plants respond to phloem-feeding insects. Most studies in plant defense have concentrated on either plant wounding, or virus and bacterial infection. Therefore, plant-defense responses to whitefly feeding were monitored. Two-month old tomato plants were infested with either silverleaf (*B. argentifolii*) or greenhouse (T. vaporariorum) whiteflies. After nine days of infestation the infested and upper non-infested leaves were harvested. These leaves were used for Northern blot analysis using radioactively labeled probes from several pathogenesis-related (PR) genes (PR1a, glucanases, chitinases, etc.), and several wound-induced genes (Lap, pin1, pin2). Whitefly feeding induced the accumulation of the PR gene mRNAs, but not mRNAs from genes regulated by the octadecanoid pathway. We have also used the technique RNA differential display to clone novel genes that are induced following whitefly feeding. After surveying many potential clones we have chosen to focus on one gene that has very high similarity to potential NADPH oxidases from other plant species. This gene (Wfi1) was induced after either species of whitefly had been feeding for 9 days. Wfi1 is also induced following ethylene treatment and treatment with methyl jasmonate. However, it is not induced following drought, salt stress or by ABA or by systemin treatments. Continued characterization of this gene and its protein product are underway in the hopes of understanding what role it might play in the larger scheme of plant defense.

**Investigator's Name(s):** W. T. G. van de Ven, T. M. Perring, & L. L. Walling.

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**Research & Implementation Area:** Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.

**Dates Covered by the Report:** To January 1999

## Genes Modulated in Silverleaf Whitefly Infested Squash

Using RNA differential display we identified 2 genes which are modulated in squash by silverleaf whitefly (*Bemisia argentifolii*) infestation. $SLW_1$ and $SLW_3$ are specifically induced in the infested and silvered leaves 3-4 weeks after infestation with silverleaf whiteflies. These genes are not induced or are induced to a much lesser extent in squash leaves infested with sweetpotato whiteflies (*Bemisia tabaci* biotype A) or non-infested leaves. $SLW_1$ and $SLW_3$ appear not to be induced by adult whitefly feeding. Both wounding and exogenously applied methyl jasmonite induced the expression of $SLW_1$. $SLW_1$ was also expressed during flower development independent of infestation with whiteflies, while $SLW_3$ was not expressed in flowers. $SLW^1$ and $SLW_3$ were further characterized by hybridization, sequence analysis and functional complementation. SLW1 encodes a 54 kD protein and has high similarity to proteins belonging to the M20B peptidase family, which are involved in hydrolyzing peptic bonds. $SLW_3$ encodes a 55 kD protein which has a high similarity to cyanogenic (-glucosidases, involved in plant defense responses to tissue damage.

## Research Summary

### Section E: Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions

Compiled by Greg Walker

Advancements continue to be made in several areas of study: breeding/screening plants for resistance to whitefly and whitefly-transmitted viruses; mechanisms of plant resistance to whiteflies; impact of plant nutrition and physiology on whitefly resistance/susceptibility; biochemical basis for plant physiological response to whitefly feeding; effect of natural plant products against whiteflies; and whitefly feeding and oviposition behavior.

*Breeding/Screening Plants for Resistance to Whitefly and Whitefly-Transmitted Viruses.* A grower-funded program for selecting alfalfa for resistance to silverleaf whitefly is in its sixth year and has developed germplasm that is much more resistant to silverleaf whitefly than current commercial cultivars. Commercial release of a new alfalfa cultivar based on this germplasm is expected within the next few years. In collards, glossy phenotypes of variety Green Glaze demonstrated high degrees of resistance to silverleaf whitefly under two different planting patterns: (1) interplantings of glossy Green Glaze and the susceptible phenotype, nonglossy Green Glaze, and (2) solid block plantings of glossy Green Glaze. In a similar test, another whitefly resistant collard, Blue Max, which has an unknown mechanism of resistance that is not based on a glossy phenotype, also showed good levels of resistance in both interplanting and solid planting patterns. In melons, 70 genotypes were screened for resistance to silverleaf whitefly. Ten genotypes were identified with possible partial resistance against silverleaf whitefly. In the genotypes screened, resistance to silverleaf whitefly and resistance to another important phloem-feeding pest, *Aphis gossypii*, were independent of each other. A standardized bioassay was developed for quantifying antibiosis and antixenosis in melon lines against silverleaf whitefly. In cotton field trials, cultivars and experimental breeding-lines of upland cotton were screened for resistance to silverleaf whitefly and to the whitefly-transmitted cotton leaf crumple geminivirus. Okra-leaf entries generally developed lower densities of whiteflies than normal-leaf entries, and Siokra L23 was the best of the okra-leaf entries. Three cotton breeding-lines were identified that had significantly lower virus symptoms than other entries. In tomato, over 80 genotypes were screened in the field for resistance to the whitefly-transmitted potato yellow mosaic geminivirus (PYMV), and partial resistance to PYMV was identified in the entries. In tests comparing the relative suitability of cotton and bean as host plants for silverleaf whitefly, whiteflies had significantly higher survival, developmental rate, pupal size, and fecundity on cotton than on bean.

*Mechanisms of Plant Resistance to Whiteflies.* As noted above, the okra-leaf trait in cotton and the glossy trait in collards have been implicated as mechanisms of resistance to silver leaf whitefly. In cotton, the role of leaf thickness and distance from the lower leaf surface to minor vascular bundles as a possible mechanism of resistance to silverleaf whitefly have been examined. In cotton field trials, the distance from the lower leaf surface to minor vascular bundles was negatively correlated with whitefly densities. In contrast, another study examined the distance from the lower leaf surface to minor vascular bundles in two cotton varieties that had markedly different levels of whitefly infestation in the field, and in this paired comparison, leaf thickness, areole area, and distance from the lower leaf surface to minor vascular bundles could not explain the difference in whitefly suitability between the two varieties. However, in this paired comparison, distance from the lower leaf surface to minor vascular bundles and areole area both may play a role in the preference of whiteflies for young leaves over mature leaves of cotton: phloem was much more accessible to whiteflies (smaller distance from the lower leaf surface to minor vascular bundles and smaller areole area) in young leaves than in mature leaves. In a non-crop solanaceous plant, *Datura wrightii*, glandular trichome density was demonstrated to be a very effective mechanism of resistance to the silverleaf whitefly in this weed species that serves as a whitefly-reservoir. This also has important implications due to the presence of glandular trichomes in some solanaceous crop species (e.g., tomato).

*Impact of Plant Nutrition and Physiology on Whitefly Resistance/Susceptibility.* In cotton, whitefly populations and honeydew production were found to increase with increasing rates of nitrogen fertilization. The impact of nitrogen fertilization on whitefly density was more apparent late in the season. Plant physiological/biochemical responses (photosynthesis, carbohydrate concentration) to the varying rates of nitrogen fertilization also were measured in an attempt to identify the mechanism in the plant that is responsible for the observed impact of nitrogen fertilization on whitefly populations. In tomato, plant stress resulting from low fertilization and/or watering resulted in poorer whitefly performance. Production of plant defensive enzymes (chitinase, peroxidase, ß-1,3-glucanase) and total phenolics in the tomatoes were measured in the different treatments. Total phenolics and peroxidase increased nearly 2-fold in two of the three stressed treatments, and may play a role in the poorer whitefly performance in these treatments. In melon, amino acid profiles were measured throughout the lifespan of leaves, from newly-formed leaves through senescence, a span of about 12 weeks. For most essential amino acids, there were two peaks, a large peak when leaves were young (1-5 wk) and a second, smaller peak during senescence (10-11 wk). Multiple regression techniques correlated some of the groupings of amino acids with positive effects on whitefly growth and others with negative effects. These analyses establish a correlation between amino acid fluctuations and whitefly performance, but do not establish causation. However, during the past year, significant improvements have been made in developing a system for culturing whiteflies on an artificial liquid nutrient medium; and this system has great potential for experimentation to determine whether fluctuations in amino acids or other nutrients are the cause of variation in whitefly performance. In the melon study, the frequency of long distance flights by whiteflies increased as the leaves became senescent. In poinsettia, whitefly adult weight and survivorship were reduced on senescent compared to vegetative host plants.

*Biochemical Basis for Plant Physiological Response to Whitefly Feeding.* Comparative analysis of amino acids in melon leaves heavily infested or lightly infested with silverleaf whitefly demonstrated that whitefly feeding creates a nutrient sink with significant elevations in total amino acids as well as 10 specific amino acids. However, the sink effect disappeared once the plants began flowering and initiating fruit set. In tomatoes, whitefly feeding resulted in accumulation of mRNA of pathogenesis related genes, but not mRNA from genes regulated by the octadecanoid pathway. Focus has been placed on characterization of the feeding-induced gene Wfi1 and its protein product (similar to potential NADPH oxidases in other plant species) to determine its role in the defense response of tomato. In squash, two genes, $SLW_1$ and $SLW_3$, were shown to be induced by silverleaf whitefly nymphal feeding, but not by adult feeding. Additionally, these genes were not induced or were only weakly induced by feeding by the closely related sweetpotato whitefly. Other factors were examined that also induce these genes. $SLW_1$ encodes a protein very similar to M20B peptidases, and $SLW_3$ encodes a protein very similar to cyanogenic glucosidases that are involved in plant defense responses to tissue damage.

*Effect of Natural Plant Products Against Whiteflies.* Several natural plant products, neem seed extract, azadiractin, and extract of bitterwood, were shown to be effective insecticides against silverleaf whitefly. Although these were applied as conventional insecticides (i.e., spray, seed or soil treatment), their origin as products of plant genes opens the possibility of inserting genes for these insecticidal compounds into crop plants as future advances in molecular biology allow.

*Whitefly Feeding and Oviposition Behavior.* Successful feeding by silverleaf whitefly nymphs always depends on stylet penetration of sieve elements in minor veins (those that have 3 xylem elements). Leaf surface features, such as lamina trichomes and elongated epidermal cells, may provide cues that guide first instar nymphs to settle over minor vascular bundles. The stylets are surrounded by a sleeve-like salivary sheath that is continuous from the leaf surface to the minor vascular bundles. The sheath is located primarily intercellularly, except in the epidermis where it can be found in epidermal cells. There was almost no evidence of stylet penetration of parenchyma or palisade cells. Detailed studies of whitefly egg insertion into plant tissue were made with light and electron microscopy. On cotton, eggs were most often laid on the lower leaf surface, generally within 30 microns of the elongated epidermal cells that are associated with vascular bundles. Eggs have a pedicel that is anchored into the plant tissue, and is inserted usually in or sometimes between epidermal cells. Sometimes the pedicel reaches as far as the mesophyll. Eggs were not observed to be inserted in stomata. Electron microscopy revealed that the distal end of the pedicel is covered with a fibrous structure that may play a role in the egg absorbing water from the leaf tissue. A cement of unknown composition is secreted onto the base of the pedicel during oviposition and serves to firmly attach the egg to the plant tissue.

**Table E. Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.**

| Research approaches | Year 1 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Characterize resistance mechanisms and identify chemical/morphological components, and study effects of insect adaptation.** | Identify potential sources of germplasm for disease, plant disorders and whitefly resistance.[a] | X | | Research was conducted on identifying potential sources of germplasm for whitefly resistance in alfalfa, cotton, melon, cole crops, and cucurbits; and resistance to virus symptoms and silverleaf disorder in cotton and cucurbits, respectively. These studies included research on plant tolerance, antibiosis, and antixenosis. Antixenosis was found not to be responsible for resistance to squash silverleaf in two zucchini lines. |
| **Develop molecular level techniques to produce resistant germplasm.** | Identify physiological processes of whiteflies to target for inhibition. | X | | Characterization of plant genomone was demonstrated in tomato and squash. Pathogenesis related mRNAs accumulated in response to whitefly feeding on tomato leaves. Data on whitefly probing behavior indicates that host evaluation phase of *Bemisia*-host interaction is dominated by probing. |
| **Incorporate resistance traits into commercial genotypes.** | Identify and isolate genetic sources of resistance for transformation and/or breeding. | X | | From promising genetic materials, inbreeds, $F_1$ and $F_2$ progenies, and assorted cultivars were studies for whitefly resistance (in alfalfa, cotton, melon and squash), and susceptibility to diseases (in cotton) and plant disorders (in squash). Including plant geneticists and other specialists on the research team has been an asset. |
| **Determine influence of host plant morphology, physiology and phenology on feeding behavior and competition.[b]** | Characterize nutritional and other preference properties of various host plants. | X | | Research was studied on the acceptability of cotton and vegetable hosts on whitefly feeding behavior. Work was conducted on distance from abaxial surface to minor veins, and feeding response on abaxial and adaxial surfaces of different hosts. |

**Table E. Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions. (Continued)**

| Research approaches | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Define whitefly feeding and oviposition behavior and investigate approaches for interrupting whitefly feeding and digestion.**[c] | Investigate approaches for interruption of feeding, assimilation, development and reproduction. | X | | The host evaluation phase of *Bemisia*-host interactions was shown to dominate by probing, and the time spent in a particular behavior was affected by imidacloprid when the whitefly came into contact with the chemical in its diet rather than on the leaf surface. Intercropping of resistant within susceptible cole crops did not lessen the abundance of whiteflies. |
| **Study whitefly toxicogenic plant reactions.** | Determine effects of whitefly feeding on host plant physiology, morphology and anatomy. | X | | Research on tomato identified a gene that is specifically induced by whitefly feeding. Four classes of genes were identified in inducing squash leaf silvering. These genes were further characterized by hybridization, sequence analysis and complementation studies. |

[a] See Table B for additional plant disease resistance research.

[b] See Section A.

[c] See Section A, approach #9.

**Table E. Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.**

| Research approaches | Year 2 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Characterize resistance mechanisms and identify chemical/morphological components, and study effects of insect adaptation.** | Determine physiological and/or morphological basis for resistance, & effects of host-plant history and insect adaptation on plant resistance to whiteflies. Continue to identify resistant germplasm. | X | | Selection for a whitefly resistant variety of alfalfa is close to completion; release of a commercial variety is expected within a few years. Whitefly-resistant or partially whitefly-resistant varieties of a number of crops have been identified, including cotton, collard, and melons. Varieties of cotton and tomato with resistance or partial resistance to whitefly-transmitted viruses also have been identified. In collards, the glossy leaf trait, and in cotton, the okra-leaf trait and large leaf surface to vascular bundle depth have been implicated as mechanisms of whitefly resistance in plants. Increased levels of phenolics and peroxidase in response to plant stress have been associated with decreased whitefly performance in tomato. In *Datura wrightii*, glandular trichomes were demonstrated to be a very effective mechanism of resistance to whiteflies. |
| **Develop molecular level techniques to produce resistant germplasm.** | Identify natural products for inhibiting processes. | X | | The natural plant products, neem seed extract, azadiractin, and extract of bitterwood, were shown to be effective insecticides against silverleaf whitefly. |
| **Incorporate resistance traits into commercial genotypes.** | Insert genes into plants[b] via plant transformation. | X | | Resistant commercial lines of alfalfa are close to release and commercial varieties of collard have been shown to exhibit whitefly resistance. Also, lines of cotton and melon have been identified with partial whitefly resistance. No progress has been made in the specific year 2 goal of inserting whitefly resistance genes into plants via transformation. |

**Table E. Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.**

| Research approaches | Year 2 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Determine influence of host plant morphology, physiology and phenology on feeding behavior and competition.**[b] | Determine the biochemical mechanism regulating adaptation to host plants. | X | | Morphological plant traits such as okra-leaf and large distance from leaf surface to vascular bundles in cotton, and glandular trichomes in *Datura wrightii* have been shown to provide partial or complete whitefly resistance. Fluctuations in amino acid concentrations over the lifespan of melon leaves were correlated with whitefly performance. Also in melons, group feeding by whiteflies was shown to create a nutrient sink in the plant, and thus provide the whiteflies with improved amino acid nutrition. Senescence in poinsettia reduces host plant quality for silverleaf whitefly. In cotton, decreased nitrogen fertilization decreases whitefly populations. In tomato, plant stress caused by fertilizer and/or water deficiency reduces host plant quality for silverleaf whitefly. |
| **Define whitefly feeding and oviposition behavior and investigate approaches for interrupting whitefly feeding and digestion.**[c] | Identify physiological and morphological mechanisms regulating processes. | X | | Improvements have been made in a system for rearing whiteflies on an artificial liquid medium. This will allow direct experimentation on the role of specific plant nutrients and allelochemicals on whitefly feeding and performance. Stylet contact with minor vascular bundles is essential for successful whitefly feeding on cotton. The fine structure of whitefly eggs and their attachment to host leaves has been studied with electron microscopy, and the distal end of the egg petiole that is inserted into the host leaves possesses morphological structures that suggest a role in water uptake from the host leaf which is a very important process for egg survival. |

**Table E.  Host-Plant Resistance, Physiological Disorders, and Host-Plant Interactions.**

| Research approaches | Year 2 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Study whitefly toxicogenic plant reactions.** | Determine biochemical basis for physiological response of plant. | X | | Genes specifically induced by whitefly feeding have been identified in tomato and in squash.  These genes may play a role in the plant's defensive response to the whitefly and/or the plant's toxicogenic reaction such as irregular ripening in tomato and silverleaf symptom in squash. |

[a] See Table B for additional plant disease resistance research.

[b] See Section A.

[c] See Section A, approach #9.

## Reports of Research Progress

### Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems

Co-Chairs: Peter Ellsworth and Steve Castle

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**Research & Implementation Area:** Section F: Integrated and Areawide Pest Management Approaches and Crop Management Systems.

**Dates Covered by the Report:** June 1997 - October 1998

### Progress in Development of IPM for Upland Cotton in Arizona Using Biorational and Biopesticide Agents for Control of Silverleaf Whitefly (SLWF) *Bemisia argentifolii* and Other Cotton Pests

An Integrated Pest Management (IPM) program that used biorational/biopesticide agents as components was tested. We need IPM cotton programs with low impacts on natural or exotic populations of beneficial arthropods in classic or augmented systems. Such IPM programs need to control all pests, with biorational agents replacing conventional chemistries and incorporate Insecticide Resistance Management (IRM) to reduce likely development of insecticide resistance. Biorational/ biopesticides "fit" IRM since usually, they require different detoxification modes as they have widely different action modes. Deltapine upland cotton was planted and furrow irrigated. In 1997, we used DP 5415. Plots were 192.5 ft. in length and 6 rows across (40-in. rows) and plots were separated by 2 fallow rows and 8 ft. alleys. In 1998, we used NuCOTN 33$^{B}$ in plots 109 ft. in length and 12 rows across (40-in. rows) and plots were separated by 4 fallow rows and 20 ft. alleys. Ground applications were made. In 1997, applications were with 3 nozzles/row; 1 overhead, and 2 with swivel nozzles angled upward on drops; and applied at 80 psi and 30 gal./ac. In 1998, applications were made by ground with 5 nozzles/row; 1 overhead, and 2 swivel nozzles angled upward on a drop on each side of the row; and applied at 250 psi and 30 gal./ac. Biorational entomopathogens against SLWF included: *Beauveria bassiana* as Naturalis®L (Troy Biosciences Inc.) 10 oz. Product/ac, 2.3x $10^{7}$ conidiia/ml; *Beauveria bassiana* as Mycotrol® (Mycotech Corp.), 0.5 lbs./ac, 2 x $10^{13}$ spores/lb.; *Paecilomyces fumosoroseus* as PFR- 97® (Thermo Trilogy Corp.), 0.025 lbs. / gal., 1x $10^{9}$ CFU (spores)/ gm equivalent 20% product. Biorational insect growth regulators against SLWF**,** at full rates as single or multiple applications, included: azadirachtin as Bollwhip™ (other action modes also, Thermo Trilogy Corp.), 4.5% formulation, at 3,6,and 9 oz product /ac in 1997and 1 rate of 6 oz/ac product in 1998; buprofezin as Applaud™ 70WP, AgrEvo, 0.35 lb. AI/ac; and pyriproxyfen as Knack™ 0.86,Valent USA), 0.54 lb. AI/ac. Applications were made once SLWF populations reached the action threshold (Univ. AZ recommendations). Biorationals used against insects other than silverleaf whitefly included: Pink bollworm sex pheromone, alone and baited with 1/10 rate chlorpyrifos; BT gene [NuCOTN 33$^{B}$]; diflubenzoran [Dimilin®]; BT sprays[e.g. DiPel®];and K salt of fatty acid [M-Pede™]. These treatments were used against pink bollworm, beet armyworm, cabbage looper, and saltmarsh caterpillar (per label). Treatments were part of a random block design that included a "Best Agricultural Practice regime" BAP, and a 1-ac block control. There were 16 treatments in 1997 and 12 in 1998. Weekly sweeps were taken in all plots for predators, parasites, and *Lygus.* In 1997*, P. fumosoroseus,* efficacies were as follows: 82.5% for eggs; 78.1 and 74.6% for small and large nymphs, respectively. These efficacies were similar to the BAP. *B. bassiana*, both products, gave excellent control of SLWF(>*P. fumosoroseus)* . The 1998 cotton season was a poor production year. SLWF populations reached action thresholds between July 27- Aug.6, 1998. Two sprays were applied in an 8-day period. Then, SLWF populations dropped sharply and did not rebound. Efficacies were as follows: against eggs; *Beauveria bassiana*, 41 and 23 % as Naturalis L®and Mycotrol®, respectively; and PFR-97, 30%; against small nymphs; *Beauveria bassiana,* 6 and 19 % as Naturalis L®and Mycotrol®, respectively; and PFR-97®; 24%; against large nymphs, *Beauveria bassiana,* 28 and 8% as Naturalis L®and Mycotrol®, respectively; and PFR-97® ,4 %. Despite these low efficacy rates, the SLWF populations remained below action thresholds. Buprofezin (Applaud™), the first and only BAP applied had egg, small nymphs, and large nymph efficacies of 28, 37, 38% respectively. This attempt need to control all pests, with biorational agents replacing conventional chemistries failed because of strong *Lygus* pressure that required one application of oxamyl, Vydate® in 1997 and several in 1998 (only1 applied). Presently, we have no biorationals for use against *Lygus*.

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**Research & Implementation Area:** Section F: Integrated and Areawide Pest Management Approaches and Crop Management Systems.

**Dates Covered by the Report:** 1998 Cotton Field Season

## Concentration and Management of *Bemisia tabaci* in Melons as a Trap Crop for Cotton

As a widely polyphagous herbivore, *Bemisia tabaci* utilizes an array of crop and non-crop hosts throughout its annual growth and decline cycle. Consistent differences in the relative abundances of *B. tabaci* on synchronously occurring hosts have strongly suggested behavioral and physiological differences in its acceptance of and performance on various hosts, respectively. Densities of *B. tabaci* recorded in both experimental and commercial field settings often have been highest in muskmelon (*Cucumis melo*) relative to cotton (*Gossypium hirsutum*) or other suitable host crops. Similar findings have been demonstrated under more controlled conditions in the laboratory or greenhouse. The potential application of such findings is that if the assortative host finding and acceptance behavior is strongly developed towards a particular host relative to others, then that host might be used to concentrate immigrating *B. tabaci* into strategically placed strips on the perimeter of and within the protected crop. Chemical control could then be concentrated just in the limited area of the trap crop while allowing natural enemies to operate unhindered by insecticides in the protected crop.

Besides possessing the necessary biological attributes for arrestment and retention of dispersing and foraging *B. tabaci* adults, a suitable trap crop must be agronomically and phenologically compatible with the principle crop. In the present study, melons were used as a trap crop with cotton as the principle crop. Both are heat tolerant, summertime crops that perform well under similar field preparation and irrigation regimes. A randomized complete block design was used at the University of Arizona Maricopa Agricultural Center to measure whitefly densities on cotton either protected by melons or unprotected without melons. Four replicate, sequential blocks were planted that consisted of 24 consecutive rows of protected cotton with 4 rows of melons planted on either side, a 12 row fallow area, and then another 24 rows of unprotected cotton with 4 rows on either side, but unplanted. A fallow area of 40 ft. separated each block. In the rows adjacent to the protected cotton, sequential plantings of melons were carried out so that robust melon plants would be present throughout the period of heaviest whitefly attack right up through the end of the cotton season. Melon plants in the 6-8 leaf stage were treated with a soil drench of imidacloprid followed by buprofezin+endosulfan and bifenthrin+endosulfan. No insecticides were applied to either the protected or unprotected cotton. The first planting of melons was disked in late July immediately following a knock-down application of endosulfan. A total of 48 leaf disks (2.5 $cm^2$) were collected weekly from each replicate (192 per treatment ) over 12 consecutive weeks (6 July-23 September). Eggs, small and large nymphs, and pupal exuviae were counted on all disks and statistically analyzed on a week by week basis.

Egg and small nymph densities on melons were more than 10-fold greater than on cotton 9 of the 12 dates. A similar magnitude of difference between the two crops was observed for large nymphs and exuviae up to the time that buprofezin was applied to melons, after which the difference declined. Density differences between protected and unprotected cotton were less distinct due partly to strong block effects. For instance, block I had higher densities of whiteflies in both treatments than the other 3 blocks. As an end block adjacent to soybean and vegetable plots, whitefly immigration into block I appeared to occur at the ends of the treatment plots where no melons were planted. In contrast, the interior blocks II and III had higher densities in unprotected cotton relative to protected cotton over much of the season. Differences between treatments in end block IV were similarly less distinct as in block I.

Experimental evaluation of the potential benefits of trap crops in reducing densities of *B. tabaci* or other pests is problematical due to non-independent treatment effects. Greater isolation between trap-crop protected and non-protected principle crops is required to minimize the influence of one treatment upon another. A second field season will attempt to examine the same two treatments, but using non-contiguous blocks with greater distance between treatment plots. A full perimeter of melons will be grown around protected treatment plots rather than on two sides only as was done for the current report.

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**Research & Implementation Area:** Section F: Integrated and Areawide Pest Management Approaches and Crop Management Systems.

**Dates Covered by the Report:** 1992 - 1997

## Upland Cotton Susceptibility to Silverleaf Whitefly Infestations

Fifteen upland cotton, *Gossypium hirsutum* L., cultivars were evaluated in the field for susceptibility to silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, in Imperial Valley, CA from 1992 to 1996. The cultivars were Chembred 232, 333, 1135, 1233, Deltapine (DPL) 20, 50, 90, 5409, 5415, 5432, 5461, 5517, 5690, Louisiana (LA) 887, and Stoneville (ST) 474. All cultivars were susceptible to whitefly infestation. Sticky cotton occurred and lint yields were low in all cultivars. In 1995 and 1996, in each case, nine untreated and insecticide-treated cultivars were compared using 4.1 adults per leaf turn as an insecticide-treatment action threshold. Lint yields of the insecticide-treated plots were from 1.2 to 7.9 X in 1995 and from 0.35 to 4.0 X in 1996 when compared to lint yields of untreated plots. On the bases of the 4.1 adults per leaf cotton threshold, DPL 5409 and 5415 on average required 5.5 insecticide applications, DPL 50, 5461, and 5517 required six applications, and DPL 5432 and 5690 required 6.5 applications. LA 887 required seven applications and ST 474 required 7.5 applications. In a no-choice greenhouse trial in 1997, equal numbers of *B. argentifolii* eggs and nymphs were produced in small leaf cages for the nine cultivars and adult emergence was not significantly different between cultivars. Results suggest the potential to reduce insecticide applications by selecting appropriate cultivars currently available. Identification of resistance mechanisms and development of breeding programs to incorporate resistance into acceptable upland cultivars appears to be a promising approach for whitefly control.

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**Research & Implementation Area:** Section F: Integrated and Areawide Pest Management Approaches and Crop Management Systems.

**Dates Covered by the Report:** 1983 - 1995

## Effects of Aldicarb on Cotton Insects and Plant Growth and Yield

Soil application of aldicarb reduced numbers of sweetpotato whitefly, *Bemisia tabaci* Gennadius, in studies conducted in 1983 and 1984, but not silverleaf whitefly, *B. argentifolii* Bellows and Perring, in studies conducted from 1988 and 1990, on upland cotton, *Gossypium hirsutum* L. Aldicarb-treated plants also had significantly fewer thrips, *Frankliniella* spp., leafhoppers, *Empoasca* spp., and damsel bugs, *Nabis* spp. early in the season, than untreated plants. Aldicarb-treated plants exhibited more vigorous plant growth than untreated plants. In mid- to late season from 21 June to 26 July in 1993 when the silverleaf whitefly population density was low (8.0 nymphs/$cm^2$ leaf disk for untreated plants) fewer silverleaf whitefly occurred on aldicarb-treated plants (4.4 nymphs/$cm^2$ leaf disk). Lint yield increase was 42% as compared to untreated plants. In 1994, when silverleaf whitefly population density was high (18.9 nymphs/$cm^2$ leaf disk for untreated plants) during mid- to late season (from 15 June to 27 July), aldicarb was not effective.

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**Research & Implementation Area:** Section F: Integrated and Areawide Pest Management Approaches and Crop Management Systems.

**Dates Covered by the Report:** 1991 - 1995

**Effects of Pyrethroid Insecticides Alone and in Mixtures on Silverleaf Whitefly and Cotton, Cauliflower, and Broccoli Yields**

Insecticide efficacy studies for silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring, control were conducted in the Imperial Valley, California from 1991 to 1995. Three studies were conducted on cotton in 1992, 1994 and 1995, one on broccoli in 1991 and one on cauliflower in 1993. Results showed that silverleaf whitefly control on cotton, broccoli and cauliflower was more effective when a pyrethroid insecticide (e.g. fenpropathrin or bifenthrin) was mixed with an organophosphate (e.g. acephate) or a cyclodiene (e.g. tralomethrin) compound as compared to either material used alone. The effect appeared to be additive toxicity of pyrethroid and a second compound with a different mode of action. Cotton lint and cauliflower yields were increased and broccoli matured earlier in pyrethroid-phosphate or pyrethroid-cyclodiene mixture treated plots as compared to plots treated with the individual chemicals alone.

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**Research & Implementation Area:** Section F: Integrated and Areawide Pest Management Approaches and Crop Management Systems.

**Dates Covered by the Report:** 1998

## Interdisciplinary Demonstration of Arizona Irrigated Cotton Production

A demonstration project was conducted on the Demonstration Farm at the Maricopa Agricultural Center. In this project all current guidelines and recommendations disseminated by The University of Arizona were integrated in a systems approach. The management decisions were made by the Extension Specialists in agronomy, entomology, irrigation management, weed sciences, and plant pathology following the University recommendations. On a 50.5 acre field 80% Bt and 20% non-Bt cotton was planted dry and watered up. Dueto the cold spring and sand-blasting, only a stand of 30,900 plants/A could be established with 84% terminal damage. A total of 72 acre-inches of water were used with 41.3 acre-inches in post plant irrigations. Weed control was achieved with one preplant application and three cultivations. Whitefly management was fully integrated with management of other insect pests. Sampling and threshold guidelines were followed for each pest. Three sprays against Lygus and one spray against whiteflies were necessary after the thresholds were exceeded. Knack¨ (pyriproxyfen) was selected for control of whiteflies based on published guidelines. No further applications were necessary for whiteflies. Our demonstration, which was located in the center of over 200,000 A of cotton in central Arizona, produced sticky-free cotton with higher than average yields and with pest management under budget. In 1998, the average number of sprays made statewide for all insects was 4.7; our demonstration required only 4. The average number of sprays required for whitefly control statewide was 1.05; our demonstration required just 1 spray. Lygus were the most chronic and yield-limiting insect in this study. Nevertheless, yields were higher than the statewide average of 1100 lbs/A, higher than the historical farm-wide average (ca. 1340 lbs/A), and higher than the farm-wide average for 1998. A total of 4120 lb seed cotton per acre was harvested, with 32.7% lint turnout (2.81 bales/A)and 45.9% seed turnout (1891 lb/A). After harvesting a field budget was established. The variable costs per acre were $915, the total cost $1266/acre. In spite of the lack of replications this project validates the usefulness and compatibility of University recommendations and the potential for integration of all disciplinary guidelines in one system.

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**Research & Implementation Area:** Section F: Integrated and Areawide Pest Management Approaches and Crop Management Systems.

**Dates Covered by the Report:** 1995 - 1998

## Whitefly Management in Cotton – A Historical Perspective

It has been less than 6 years since the devastation of the whitefly in Arizona and southern California. Numbers were so dense that windshields were clouded with the bodies of the adults, unprotected cotton fields were "biologically" defoliated, and fields stood in "permanent" wilt due to the excessive stress imposed by the immatures. Today our program has evolved from an effective, yet 2-dimensional system of chemical management to a multi-faceted, 3-dimensional and integrated management strategy. Early on the three "keys" to whitefly management were identified by us and others as 1) Sampling and detection, 2) Effective chemical use, and 3) Avoidance of the problem. Now, this matrix of factors can be represented in the form of a pyramid, an inherently stable structure. "Avoidance" is the foundation block upon which "Effective Chemical Use" and "Sampling" rest. Confronted with a pest crisis, short term survival depends on the upper two levels of the pyramid. However, sustainable, long-term strategies ultimately must depend on the development of a solid foundation, "avoidance." At the same time, a pyramid-strategy developed for one pest must be compatible with like strategies in place for all pests of a system.

The building blocks of a successful pest management program can be further subdivided into component parts. Sampling in cotton involves multi-stage and binomial methods of classifying whitefly populations. These tools have been adapted for new chemistry as it was developed. Effective chemical use consists principally of the use of action thresholds, availability and understanding of selective and effective chemistry, and a proactive resistance management plan. Action thresholds have been developed that are effective at preventing yield and quality losses. These, too, are insect stage-specific and have been optimized for proper deployment of insect growth regulators (IGRs). The IGRs, Knack and Applaud ,became available for the first time in this country in 1996 and have had a sensational impact on the selective management of this pest. [However, one cannot understate the importance of concomitant use of Admire (imidacloprid) in melons and vegetables to the overall, area-wide lowering of pest dynamics.]All chemistry has been organized into a 3-stage program of deployment for resistance management. The proactive nature of this program has led to the restriction of use of the new IGRs such that their modes of action may be preserved for as long as possible while providing relief for resistance risk to all products.

Adoption of IGRs and their proper use has been exceptional with over half to two thirds of all cotton acres being treated annually since 1996. The challenge remains, however, to further delve into the foundation block of our management program, avoidance. This level of management may be subdivided into three interrelated tiers of development, Cross-Commodity Cooperation, Exploitation of Pest Biology, and Crop Management. Key elements within these tiers are either in partial operation or development at this time. Dramatic successes so far — 6.6 sprays against whiteflies in 1995 down to just over 1 spray in 1998 —overshadow efforts to continue development of tactics of avoidance. Complacency in growers and the scientific community is a very real challenge to us now. Work should continue in all areas of avoidance; however, an opportunity has become available to make significant progress in cross-commodity cooperation with specific impacts on crop placement, alternate host management (source reduction),and inter-crop movement. As we build and strengthen our pyramid of whitefly management in cotton, we need to build similar structures of whitefly management for the other major crop hosts in Arizona(e.g., melons and vegetables). Only then can we fully realize an integrated, systemic, and sustainable solution to this highly mobile pest. Palumbo et al. (this volume) reported on just such an effort to rationalize chemical use and whitefly management among the major crop host commodities in Arizona. Their initial efforts will be to interlock resistance management programs among four host crops, spring melons, cotton, fall melons, and vegetables. The challenge remains to preserve our successes while redoubling efforts to develop and integrate more tactics of avoidance.

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**Research & Implementation Area:** Section F: Integrated and Areawide Pest Management Approaches and Crop Management Systems.

**Dates Covered by the Report:** August 1997 - December 1998

## Effectiveness of Living Ground Covers for Managing Spread of Geminiviruses in Tomato by *Bemisia tabaci* in Costa Rica

Staked tomatoes in Costa Rica are grown mainly on small plots (<0.5 ha) and often severely affected by the Tomato Yellow Mottle Virus (ToYMoV), vectored by *Bemisia tabaci* biotype C. The impact of the disease on crop yield depends on plant age at time of infection, and is greatest during the first eight weeks after germination. Therefore, management should focus on minimizing contact between the vector and the tomato plant during this period. Consequently, a two-phase preventative management scheme has been proposed: (1) protection of seedbeds with fine netting (Tildenet IN50, Tildenet Ltd., Arkansas) to produce high-quality, virus-free seedlings, and (2) masking the crop after transplanting from immigrating viruliferous whiteflies with living ground covers. This second phase is presently under investigation. Living ground covers are locally available, economical to establish and could provide resource-poor tomato growers with extra income through sale of seed, forage, or other products, organic matter to enrich the soil, and refugia for beneficial insects.

Three field experiments were recently conducted, one in Turrialba (Caribbean watershed) and two in Grecia (Pacific watershed), Costa Rica. Each experiment was actually a replicate of a single experiment to be replicated four times. A total of about 2400 $m^2$ in each location was divided into six, 400 $m^2$ plots randomly assigned to six ground cover treatments: *Arachis pintoi* (perennial peanuts) (Leguminosae), "cinquillo" (*Drymaria cordata*, Caryophyllaceae), coriander (*Coriandrum sativum*, Umbelliferae), silver plastic, bare ground treated with imidacloprid (commercial standard), and bare ground untreated (absolute control). Living covers were established well before tomatoes were transplanted. Silver plastic (silver/black, coextruded, 56" x 1.25 Mls; Olefinas S.A., Guatemala) was put in place over the 30 cm-wide bed two weeks before transplanting. Imidacloprid (Confidor 70 WG; Bayer) was applied to the foliage at the recommended rate (9 g/ 40 $m^2$ of seedbed surface) a week before transplanting, and two drench applications (250 g/ha) two and four weeks later. No other insecticides were used in any plot during the rest of the season.

So far, silver plastic has been the best treatment in terms of reduction of incoming whitefly adults, delay of ToYMoV dissemination, reduction of disease severity, and highest tomato yields. It was followed by living covers, but their degree of effectiveness varied with each experiment. For Guayabo, area under the disease progress curve (AUDPC) was calculated for disease incidence at 2594 (silver plastic), 2027-2864 (living covers), imidacloprid (3290), and 4149 (bare soil), and for disease severity at 951, 791-1087, 1611, and 2402, respectively. Yields were 46, 25-40, 25 and 5 t/ha, respectively. For Grecia (I), corresponding AUDPC values were 511, 553-2845, 2002, and 5197 for disease incidence, and 260, 294-1624, 1170 and 3378 for disease severity. Yields were 28, 12-16, 11 and 10 t/ha, respectively. Vector pressure was highest during the second experiment at Grecia where the experimental plot was very close to a 2.5-ha commercial field heavily infected by the ToYMoV. There values for both disease incidence and severity were large for all treatments (1323-3899 and 512-2651, respectively) and yields were poor (1-13 t/ha).

Thus, both living and inert covers provided effective control of whitefly colonization and ToYMoV spread under moderate whitefly pressure, but control broke down under extremely high pressure. This result underlies the need to supplement both preventative and curative management tactics applied by the individual grower with area-wide preventative approaches, such as planting dates and crop-free periods, in order to successfully manage whitefly-vectored geminiviruses in Costa Rica.

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**Research & Implementation Area:** Section F: Integrated and Areawide Pest Management Approaches and Crop Management Systems.

**Dates Covered by the Report:** June 1995 - October 1998

**Summary of Standardized Survey of Whitefly in the Gila Basin Near Gila Bend, AZ**

A standard survey for whitefly adults was initiated in June 1995 as part of a grower initiated Integrated Pest Management Project. Field survey protocol used was the method developed by the University of Arizona. In 1995, data collected included adult whitefly density, planting date, variety and applications of insecticides. In 1996, whitefly nymphs were included in the survey. In 1997, the area surveyed included all of the fields in the Gila Basin. In 1998, forty fields of uniform age were select representing all areas of the basin. Each field was sampled once per week for 18 weeks.

Whitefly adults during 1995 were treated beginning in early July and continued for the remainder of the cotton-growing season. Fields averaged 5.2 treatments with combinations of up to five insecticides with little or no whitefly control achieved. On the average field were infested (>40% based on binomial leaf turn method) for an average of 5.1 weeks. In 1996 insect growth regulators, pyriproxyfen and buprofezin and genetically engineered cotton, with the 'Bt' gene, was introduced into the basin. Field applications of insecticide for whitefly dropped dramatically to 1.9 treatments and averaged only 1.3 weeks above the 40% threshold for adults only. When both adults and nymphs were used as recommended the period above the threshold was only 1.0 weeks. In 1997, the average number of treatments per field held constant at 1.9 per field. The number of weeks adults were above the 40% threshold was 1.4 weeks but the nymphs were above the threshold for 3.7 weeks. In 1998 the fields averaged 1.8 treatments for whitefly per field. The number of weeks that the fields were above threshold increased to 2.4 for adults and 4.4 for nymphs. In general, the introduction of the insect growth regulators and the genetically altered cotton has resulted in lower whitefly populations.

Seasonal variation in weather conditions may also play a role in the timing and occurrence of whitefly population outbreaks.

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**Research & Implementation Area:** Section F: Integrated and Areawide Pest Management Approaches and Crop Management Systems.

**Dates Covered by the Report:** June 1984 - October 1997

## Integrated Management of *Bemisia tabaci* Genn (Aleyrodidae) and Yellow Moaisic Virus in Mothbean (Vigna aconitifoia ) Crop

The whitefly, *Bemisia tabaci* Gen. is a serious pest on leguminous crops in tropical and subtropical countries. Losses due to whitefly and YMV in pulse crops are estimated from 25 to 73% in different cultivars of Vigna spp. During favourable high temperatures of arid zone in India, the rate of whitefly reproduction is also high and the position of adults and immature stages on the underside of leaves has made this pest difficult to control. Increasing use of synthetic pesticides leads to serious problems like environmental pollution and insect resistance to insecticides. Therefore methods involving various agronomical practices, screening for pest resistance and use of plant products like neem extract, neem oil and neem seed powder were studied and an integrated approach for management of whitefly and YMV is suggested so that the use of pesticides is minimized.

The whitefly usually started attacking the crop from 3 rd week of August and the incidence of peak period of activity was 6.3-8.3/plant/catch. This insect becomes more serious pest as it also acts vector of yellow mosaic virus. Since the chlorophyll pigments of the leaves are destroyed, the photosynthesis is severely hampered and thus results in low productivity of crop. This results a loss of 15 to 50% loss in yield under different climatic conditions. In general, the loss in grain yield was minimum for the crop sown in first or second week of July.

Field screening of promising fifty-one cultivars of mothbean was carried out against *Bemisia tabaci* and YMV. Twenty-two cultivars so selected were subjected to series of stress trials. Seven cultivars viz. IPCMO-943, IPCMO-1035, T-16, T-2, Jadia, PLMO-240 and PLMO-216 were isolated to be the least susceptible to the pest and YMV.

Field trials conducted with neem products in providing pest protection umbrella to pulse crops highlights the need for better understanding for the use of these ecofriendly products which are efficient antifeedant and repellent to pest attack. The results on whitefly population varied significantly in different treatments. Use of monocrotophos was superior to all treatments followed by neem oil, neem seed extract (5%), neem seed kernel extract (2%) and neem seed extract (2%). The use of neem oil performed better than the aqueous extracts in reducing the population of whitefly. Subsequently, there was significant reduction in YMV infection in mothbean crop. Increase of 20-55% grain yield was recorded under arid zone cultivation of mothbean. The study thus revealed that these plant products may be suitably incorporated in the IPM programme of mothbean. These extracts are cost effective as all the raw material is locally available which can easily be exploited by the farmers for its use against whitefly and YMV.

**Research Summary**

**Integrated and Areawide Pest Management Approaches and Crop Management Systems**

Compiled by Steve Castle

Section F provides a forum for the synthesis of ideas and approaches to integrated and areawide crop and pest management. It encourages the exploration and development of multiple control tactics that draw from the component areas of applied management covered by Sections C, D, and E, but also from the basic and applied research areas covered by Sections A and B. As advancement continues in each one of these areas, it would appear that there is unprecedented opportunity to incorporate biological, chemical, cultural and host plant resistance elements into field experiments towards the development of fully integrated whitefly management. Much of the groundwork has been laid for carrying out and evaluating integrated approaches through the development of tools and techniques that are now well established. For example, sampling protocols developed for adults and nymphs in cotton and melons would allow robust estimates of whitefly densities as part of an evaluation of different multitactical management approaches. The deployment of narrow spectrum insecticides presents much greater opportunity for augmentative biocontrol using various techniques such as 'banker' plants to distribute natural enemies. Establishment of exotic parasitoids in the southwest, helped along by year-round cultivation of natural enemy refuges, holds the possibility of more effective regulation of whitefly populations throughout the year. One possible merging of tactics with synergistic potential would be the deployment of resistant cultivars to slow the growth rate of whitefly populations in combination with augmentative releases of natural enemies. Progress in the development of resistant cultivars of alfalfa, cotton and melons could greatly enhance the capacity of natural enemies to regulate whitefly populations and reduce incidences of viral disease. Synergy among pest control tactics becomes more likely as multiple pest management approaches are employed.

There were evaluations from each of the other five sections this year of combined tactics directed against whiteflies, or in some cases a consideration of the impact of multiple factors on whitefly densities. Life table studies of *Bemisia tabaci* in 1997/98 Arizona cotton fields subjected to different insecticide regimens were reported in Section A. The relative contribution of various mortality factors on egg and nymphal cohorts were summarized from a total of 10 life tables, indicating that predation represented the largest fraction of mortality and that egg and 4$^{th}$ instar nymphs suffered the highest stage-specific mortalities. The merit of this type of approach is that it precisely identifies the specific mortality factors, but from a Section F perspective, also provides valuable insight into the interaction of specific mortality factors such as insecticides and predation/parasitism. In Section B, a more subtle type of interaction was examined that involved the influence of geminivirus infection of tomato and/or infestation by whiteflies on the subsequent feeding and development of whiteflies and other insect herbivores. Differences in whitefly oviposition occurred on plants depending upon whether whitefly feeding had taken place or if they were infected with tomato mottle virus, with both treatments having had significantly fewer eggs than virus-free, uninfested plants. PR protein titres also were affected according to the infestation/infection status of the test plants, a result that may support the eventual development of treatments that elicit plant responses suppressive to whitefly populations. In a straightforward testing of combined tactics reported in Section C, the mixture of the bioinsecticide *Beauvaria bassiana* with the chloronicotinyl insecticide imidacloprid produced an unexpected inhibitory effect, measured as percentage decline in whitefly densities, compared to when imidacloprid was used individually. An analogous study was reported in Section D, but in this case was concerned with the potential impact of *B. bassiana* applications on populations of natural enemies. Although no significant differences in numbers of predators in untreated plots compared to *B. bassiana*-treated plots were observed on any sampling dates, predators collected in the *B. bassiana*-treated plots and retained in the laboratory showed significant mortality compared to those collected in untreated plots. These results serve the warning that so-called biorational insecticides may still have significant adverse effects on beneficial insect populations, and thereby emphasizes the pest-suppressive capability of a spray treatment to be of paramount importance if both conventional and biorational treatments affect natural enemies deleteriously. Differences in responses of parasitoids to whitefly nymphs according to plant host were observed in greenhouse studies that showed fewest numbers of parasitoids foraged on collards relative to either cowpeas or cotton, thus corroborating previous observations of lower parasitism rates on cruciferous crops observed in the southwestern U.S. Finally, in Section E, the influence of agronomic practices on whitefly population densities was demonstrated in a field study that examined the affect of different nitrogen fertilization rates in cotton on whitefly infestations. Increasing rates of nitrogen resulted in higher densities of whiteflies and honeydew drops produced by whiteflies, thus suggesting the need to balance inputs into crop production between those necessary to maximize yields with those that can help to avoid damaging pest infestations.

**Philosophies**

As the keynote address for Section F this year, Palumbo et al. presented an Arizona grower-initiated model for cross-commodity planning and cooperation with respect to managing whiteflies and sustaining long-term insecticide efficacies. The historical progression of insecticides registered for use against whiteflies on different crops was detailed, leading up to the present situation of certain insecticides being available for multiple crop use throughout the year. Concerns raised by growers and researchers alike over possible resistance risks stimulated the leadership of two growers organizations to convene a hearing involving representatives from vegetable and cotton grower organizations as well as University of Arizona researchers. Still in a developmental stage, data for crop production, insecticide use patterns, and simulated whitefly population dynamics are being compiled towards the ultimate goal of harmonizing chemical use across commodities. This ongoing effort in Arizona is significant for a number of reasons. First, it recognizes the potential conflict of using insecticides across commodities and therefore represents a proactive approach to managing pests, crops, and chemical control strategies. Second, the awareness shown by the growers in recognizing the potential conflict and their initiative in convening a working group to promote beneficial crop/insecticide use patterns represents progressiveness in agriculture and pest/crop management. Third, the grower/researcher alliance formed to tackle this complex issue is not only a validation of the basic model put forth by the original establishment of state experiment stations and their extension services, but also of the quality of the interaction between growers and researchers in Arizona and the progress that has been achieved in silverleaf whitefly management. The transfer of research findings generated by university and government scientists through extension channels to growers has transformed the silverleaf whitefly from an outbreak pest into, as Palumbo et al. state, a managed pest. By initiating further communications in an effort to harmonize chemical use at a time when silverleaf whitefly infestations have been rendered relatively benign,growers have affirmed the progress made in silverleaf whitefly management as well as the working model that made possible the progress.

As a prelude to the keynote address, Ellsworth presented much of the background behind the successful management of silverleaf whitefly in Arizona cotton. He characterized whitefly management as being dependent upon a matrix of factors that were represented in the form of a pyramid. Conceptually, the pyramid consisted of three basic levels with Avoidance as the foundation level, Effective Chemical Use as the center level and Sampling at the top level of the pyramid. From top to bottom, each level of the pyramid was progressively more subdivided into specific categories of management. Ellsworth emphasized that whereas a large amount of specific information has been developed for the Sampling and Effective Chemical Use levels of the pyramid, the challenge remains to generate sustainable, long-term strategies that are compatible with like strategies for other pests. To accomplish this requires further development of the Avoidance level.

**Development**

Hilje and Stansly reported on the use of living ground covers for managing spread of geminiviruses in tomato. Living ground cover is the terminology they use to refer to a protective crop that is intercropped with a principal crop, in this case for the purpose of interfering with the spread of whitefly-transmitted viruses. In addition to three different plant types used as ground covers, imidacloprid, silver plastic as a mulch cover, and bare ground were used in field experiments. The greatest reduction in numbers of incoming whitefly adults and viral disease was observed with the silver plastic followed by the living ground covers and then imidacloprid. Under conditions of high whitefly pressure, however, the preventive measures represented by the silver plastic and living ground covers were unable to avoid heavy colonization and viral disease spread. Along the same lines of research, Castle explored the use of melons as a protection crop for cotton. The basic objective was to concentrate and manage whiteflies within the trap crop only while allowing natural mortality forces to operate in the cotton. Much higher numbers of whiteflies were recorded in melons compared to cotton, but differences among melon-protected or unprotected cotton plots were not consistent.

Chu reported that cotton plant growth and yields increased with soil applications of aldicarb during moderate, but not heavy, whitefly infestations; pyrethroid mixtures with organophosphates or cyclodienes resulted in increased control of whiteflies over any of the compounds used individually; the number of insecticide applications (based on an adult threshold of 4.1 per leaf turn) in cotton could be decreased depending on cotton cultivar planted, although a no-choice experiment in the greenhouse failed to show any differences among these cultivars in adult emergence.

Whereas most appraisals of various control tactics are done in small-scale experimental plots, larger-scale surveys of annual whitefly population trends help with the appraisal of the impact that predominant management tactics used in a particular year had relative to other years. For example, Jech reported that an average of 5.2 insecticide applications were applied in 1995 Arizona cotton fields. Following the Section 18 registration of buprofezin and pyriproxyfen in 1996, insecticide applications dropped to an average of 1.9 treatments for the entire year. The same average number of applications were made in 1997, but dropped slightly to 1.8 in 1998. It is apparent from this survey and other sources that whitefly management in Arizona cotton has improved greatly since 1995.

**Integration**

An ambitious effort to utilize biorational and biopesticidal agents for control of silverleaf whitefly and other cotton pests was discussed by Akey and Henneberry. The central objective was to utilize non-conventional materials when necessary for control of the primary pests in order to foster activities of beneficial arthropods, but also towards the goal of incorporating them into insecticide resistance management strategies. Effective biorational/biopesticidal products are available for all major pests in Arizona cotton but for the exception of *Lygus* spp. Against silverleaf whiteflies, *Beauveria bassiana* and *Paecilomyces fumosoroseus* were used as entomopathogens, while the insect growth regulators buprofezin and pyriproxyfen were also employed. Results were not reported for all treatments, in part because of an unusual whitefly season in 1998.

A similar effort to utilize biorational insecticides in addition to resistant cultivars of mothbean to avoid whitefly outbreaks and epidemics of yellow mosaic virus (YMV) was reported from India. Combined losses in pulse crops due to whitefly and YMV often range between 25-73%. Concerns about environmental pollution and insect resistance to insecticides stemming from an overuse of synthetic insecticides led Vir to try indigenous botanical products such as neem extract, neem oil and neem seed powder to combat whiteflies and impede the spread of YMV. However, superior whitefly control was achieved through the use of monocrotophos relative to any of the neem products, although the neem oil helped to significantly reduce the incidence of YMV. Vir concluded that the neem products could still be incorporated into an IPM program for mothbean.

**Delivery & Implementation**

The presentations by Palumbo et al. and Ellsworth on IPM and IRM strategies for whiteflies pointed to the signifcant progress in whitefly management that has been made over the past 5-8 years in Arizona. Only the briefest of lapses is required to become complacent about the transition from the outbreak year of 1995 to the controlled years of 1996-98 and lose sight of the tremendous planning, education, and cooperation that was required in order for so radical and successful shift to take place. The IPM and IRM programs built around the IGRs buprofezin and pyriproxyfen required years of field-trial experience with both products in order to work them into a comprehensive and viable management strategy. Once an implementation formula was arrived at, it then required an exhaustive training and education program for growers and PCAs in all parts of the state so that maximum benefit would be gained from both products that so strikingly departed from conventional products in terms of their whitefly-killing characteristics. The extraordinary discipline that has been practiced by growers for 3 consecutive years to enable the most effective timing and use of both products is a tribute to the expert delivery and implementation by the Arizona IPM and IRM programs for whiteflies. The point made earlier about the significance of growers initiating proactively a program to harmonize insecticide use is the ultimate validation of the Arizona IPM/IRM program for whiteflies: responding to previous excellence and success in resolving a crisis, growers have now initiated planning for further delivery and implementation.

**Table F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems.**

| Research Approaches[a] | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Development:** | | | | |
| **Study whitefly-crop interactions[b] as cultural components that affect population dynamics, e.g., water, nutrients, plant population, planting/termination/harvest dates, other farm practices, intercrop relationships.** | Identify potential beneficial or exacerbating farm practices or inputs for testing. | X but limited | | Only minor progress has been made on this approach (since last 5-yr review), & mainly in area-wide programs. This work is correlative, & little experimental work has been planned for or reported. Past work identified the potential or described the role of fertility status, water-stress & some other agronomic factors on *Bemisia* population dynamics. Conceptual discussion was presented on the role of pesticidal & non-pesticidal factors on *Bemisia* outbreaks. |
| **Develop behavioral barriers[b] to whitefly colonization and population development, e.g., mulches, trap crops, inter-cropping, row covers, etc.** | Review potential behavioral disrupters and evaluate as potential IPM components. | X | | Progress has been made in several areas:<br>C row covers and screens as physical barriers,<br>C mulches and oils as behavioral barriers,<br>C living mulches as behavioral barriers. |
| **Integration:** | | | | |
| **Develop Integrated Pest Management[c] systems using dual or multiple control tactics, e.g., cultural, biological, chemical, host plant resistance, etc.** | Identify candidate dual or multiple control tactic systems, e.g., IGRs and natural enemy conservation. | X | | Significant activity on this goal has occurred:<br>C Insect Growth Regulators & biological control in cotton (conservation)<br>C imidacloprid & other chemical control tactics & various forms of biological control, especially in vegetables<br>C studies of direct & indirect effects of chemical control on bio-control agents. |

**Table F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems. (Continued)**

| Research Approaches[a] | Year 1 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Integrate sampling with other key components of IPM systems, e.g., thresholds, economics, decision-making, biological control, etc.** | Develop or modify sampling systems for new crops; integrate with thresholds and decision-making. | X | | Limited progress has been made in this area:<br>C *Bemisia* distributions have been examined in tomato,<br>C new binomial sampling system for large nymphs in cotton, & integration with thresholds for IGR decisions<br>C sampling & IGR re-treatment decisions tested in cotton. |
| **Delivery and Implementation:** | | | | |
| **Elevate single field/farm practices to areawide community-based contexts; develop methodology for installing and evaluating areawide control technologies and their impact.** | Identify agricultural communities amenable to areawide management; conduct thorough pre-implementation evaluation. | X | | Significant progress was made in this area mainly in cotton:<br>C areas dominated by cotton were identified in AZ & CA for implementation of cooperative programs.<br>C areas of melon and vegetable production were identified in TX for potential area-wide programs.<br>C area-wide sampling, & decision-making was the main focus of most programs; however, coordinated natural enemy releases were also conducted. |
| **Implement and deliver Integrated Pest Management and Integrated Crop Management systems or system components to clientele.** | Develop and distribute provisional IPM & ICM recommendations. | X | | Continued progress was made in this area:<br>C IPM recommendations were distributed AZ, CA, Mexico & FL; bilateral discussions between Brazil & U.S. took place.<br>C IPM & ICM guidelines were coordinated in AZ cotton. |

[a] See Tables A to E for additional complementary research.
[b] See Tables A for additional complementary research.
[c] See Tables E for additional complementary research.

**Table F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems.**

| Research Approaches[a] | Year 2 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Development:** | | | | |
| **Study whitefly-crop interactions[b] as cultural components that affect population dynamics, e.g., water, nutrients, plant population, planting/termination/harvest dates, other farm practices, intercrop relationships.** | Determine nature and character of relationship between interaction and whitefly population dynamics. | X | | Nitrogen fertilization at different rates in cotton and its impact on whitefly population densities and honeydew deposition was studied. Considerable development occurred on cross-commodity integration of pesticides used in multi-cropped situations and in conceptualization of the multiple levels and factors upon which whitefly management depends. |
| **Develop behavioral barriers[b] to whitefly colonization and population development, e.g., mulches, trap crops, inter-cropping, row covers, etc.** | Conduct field-level trials; quantify impact to crop and whitefly dynamics | X | | Investigations on intercropping took place in both desert and tropical environments. Although reductions in whitefly densities were observed in both systems, further experimentation is required to establish the effectiveness of the trap crops relative to more conventional management techniques. |

**Table F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems. (Continued)**

| Research Approaches[a] | Year 2 Goals Statement | Progress Achieved Yes | Progress Achieved No | Significance |
|---|---|---|---|---|
| **Integration:** | | | | |
| **Develop Integrated Pest Management[c] systems using dual or multiple control tactics, e.g., cultural, biological, chemical, host plant resistance, etc.** | Initiate field testing of candidate systems. | X | | A number of field studies employed multiple tactics directed against whitefly populations. Biorational insecticides were examined in combination with IGRs and other biopesticidal agents such as *Beauvaria bassiana* for control efficacy of silverleaf whitefly. There was an indication of inhibitory action by *B. bassiana* when used in combination with imidacloprid as well as deleterious effects to predators contacted by *B. bassiana* treatments. Neem products were used to reduce whitefly populations and incidence of yellow mosaic virus in India. A melon trap crop was integrated with chemical control to focus potentially disrupting treatments into a limited area while preserving natural mortality factors in cotton as the principle crop. |
| **Integrate sampling with other key components of IPM systems, e.g., thresholds, economics, decision-making, biological control, etc.** | Establish practical utility of system through economic analyses; field efficiencies and costs. | X | | Analysis of types and patterns of chemical treatments made on a large number of cotton fields in central Arizona over a 4 year period revealed extraordinary differences in the number of treatments and amount of time that whiteflies exceeded threshold levels prior to and following the advent of the IGRs buprofezin and pyriproxyfen. The proactive initiative taken by Arizona growers to pursue chemical use harmonization across commodities required consideration of all aspects of pest and crop management. A similar whole system appraisal was made in the San Joaquin Valley with an emphasis on integrating multiple practices with diverse insecticide classes as part of an insecticide resistance management program. |

**Table F. Integrated and Areawide Pest Management Approaches, and Crop Management Systems. (Continued)**

| Research Approaches[a] | Year 2 Goals Statement | Progress Achieved Yes | No | Significance |
|---|---|---|---|---|
| **Delivery and Implementation:** | | | | |
| **Elevate single field/farm practices to areawide community-based contexts; develop methodology for installing and evaluating areawide control technologies and their impact.** | Install control technologies into community; develop systems for evaluation. | X | | Large areas in the San Joaquin Valley observed specific guidelines for IPM and IRM in cotton with evaluations continuing on the benefits attained over areas that did not observe these guidelines. Community wide evaluations were made on quality of whitefly management according to chemical control practices. The successful IPM and IRM programs practiced in Arizona cotton continued for a third consecutive year. Further cross-commodity develoment of these programs is under way. |
| **Implement and deliver Integrated Pest Management and Integrated Crop Management systems or system components to clientele.** | Conduct whole farm/operation demonstrations of IPM systems. | X | | A 'best agricultural practices' demonstration project was conducted on 50.5 acres at the University of Arizona Maricopa Agricultural Center that included inputs from extension specialists in agronomy, entomology, irrigation management, weed sciences and plant pathology according to university recommendations. Whitefly management was fully integrated with management of other insect pests and required only a single application of pyriproxyfen. Lint yields of 2.81 bales/acre were higher than the historical as well as the 1998 farm-wide average. An integrated areawide management program involving the cooperation of growers, PCAs, ginners and state and university researchers was expanded during a second year in the San Joaquin Valley. |

[a] See Tables A to E for additional complementary research.
[b] See Tables A for additional complementary research.
[c] See Tables E for additional complementary research.

**Appendix A - Bibliograph of *Bemisia Tabaci* and *Bemisia argentifolii* Bellows and Perring**

# ADDENDUM

## Bibliography of

## *Bemisia tabaci* (Gennadius)
## &
## *Bemisia argentifolii* Bellows and Perring

**Steven E. Naranjo**
**George D. Butler, Jr.**
**Thomas J. Henneberry**

**January 1999**

**Bibliography of *Bemisia tabaci* (Gennadius) and *Bemisia argentifolii* Bellows & Perring**

Addendum, January 1999

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In 1995 we published a bibliography of *Bemisia tabaci* (Gennadius) and *Bemisia argentifolii* Bellows & Perring (Butler et al. 1995). This bibliography was compiled from various sources including the current awareness literature service of the National Agricultural Library, Current Contents (Institute for Scientific Information), the two published bibliographies of Cock (CAB International), and the proceedings of several international conferences and symposia. It attempted to cover the world literature through the end of 1994. Addenda to this bibliography were published in 1996, 1997 and 1998 (Naranjo et al. 1996, 1997, 1998). This 4th addendum includes citations listed during 1998.

We alert users of this bibliography to several points. First, we have not attempted to abbreviate many of the names of non-US publications and have spelled out some names, especially USA state names. Second, we have not been able to obtain copies of some of the citations and so could not verify spelling, scientific names, irregular punctuation, and accuracy of the location of the reference. We have tried to standardize as much as possible, but our references may not be exactly as given in the original publications.

To simplify the distribution of electronic copies, we maintain the January 1999 addendum and the total bibliography (through January 1999). This permits those with the complete database from last year to update through the end of 1997 and those without any of the versions to obtain the entire bibliography. We offer several options for obtaining electronic copies. For those that send us a blank diskette and mailer, we will provide copies of the databases in Procite format (please specify *V. 2.*for DOS or *V. 4.03* for Windows 95) word processor format (Word 7.0) or ASCII text format. We can also provide the databases along with a runtime version of the Procite software (please specify *V. 2* for DOS or *V. 4.03* for Windows 95). This runtime software will enable you to search and print the database. Finally, you can download any of the formats mentioned above from the Western Cotton Research Laboratory World-Wide-Web Homepage, **http://pwa.ars.usda.gov/wcrl/**. Comments and suggestions can be addressed to SEN at **snaranjo@ix.netcom.com**

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**Appendix B: Meeting Agenda**

**SECOND ANNUAL PROGRESS REVIEW FIVE-YEAR SILVERLEAF WHITEFLY RESEARCH, ACTION, AND TECHNOLOGY TRANSFER PLAN**
**Agenda**

**Sunday, January 31, 1999**

| | | |
|---|---|---|
| 8:00 a.m. | Poster set-up begins and Registration (SOUTH ATRIUM) | |
| 1:00 p.m. | Welcome and Announcements (PUEBLO ROOM) | *Walker Jones & Thomas M. Perring* |
| 1:15 p.m. | Charge to Conference | *Robert Faust* |
| 1:30 p.m. | Section B—Paper Presentations | Co-Chairs: *Bob Gilbertson & Robin Huettel* |
| 2:50 p.m. | Section B—Discussion | |
| 3:20 p.m. | Break | |
| 3:30 p.m. | Section C—Paper Presentations | Co-Chairs: *James Brazzle & Phil Stansly* |
| 4:50 p.m. | Section C—Discussion | |
| 5:30 p.m. | Mixer and Poster Session (SOUTH ATRIUM) | |

**Monday, February 1, 1999**

| | | |
|---|---|---|
| 7:00 a.m. | Continental Breakfast (SOUTH ATRIUM) | |
| 8:00 a.m. | Section E—Paper Presentations | Co-Chairs: *Alvin Simmons & Greg Walker* |
| 9:20 a.m. | Section E—Discussion | |
| 9:50 a.m. | Break | |
| 10:00 a.m. | Section F—Paper Presentations | Co-Chairs: *Steve Castle & Peter Ellsworth* |
| noon a.m. | Section F—Discussion | |
| 12:30 p.m. | Lunch | |
| 2:00 p.m. | Section D—Paper Presentations | Co-Chairs: *James Hagler & Charlie Pickett* |
| 3:30 p.m. | Break | |
| 3:40 p.m. | Section D—Paper Presentations (continued) | |
| 4:30 p.m. | Section D—Discussion | |
| 7:00 p.m. | Sticky Cotton Bulletin Working Group (PUEBLO ROOM) | |

**Tuesday, February 2, 1999**

| | | |
|---|---|---|
| 7:00 a.m. | Continental Breakfast (SOUTH ATRIUM) | |
| 8:00 a.m. | Section A—Paper Presentations | Co-Chairs: *Rufus Isaacs & Steve Naranjo* |
| 9:30 a.m. | Section A—Discussion | |
| 10:00 a.m. | Break | |
| 10:15 a.m. | Progress Review—Sections A, B, C & D | Moderated by: *Section Co-Chairs* |
| 12:15 p.m. | Lunch | |
| 2:00 p.m. | Progress Review—Sections E & F | Moderated by: *Section Co-Chairs* |
| 3:00 p.m. | General Discussion | |

Immediately following the end of the General Discussion period, the Working Group Committee will meet. The Program Planning and Review Committee meeting will take place immediately following the Working Group.

**Section A: Biology, Ecology, and Population Dynamics**
**Co-Chairs: Rufus Isaacs and Steve Naranjo**

*Characterization of fourth instar greenhouse whiteflies, Trialeurodes vaporariorum: developmental markers and ecdysteroid fluctuations*
Gelman, D.B., M.B. Blackburn, J.S. Hu, & J. Bentz

*Heat shock proteins in whiteflies*
Salvucci, M.E.

*Bemisia argentifolii egg distribution on leaves of cotton varieties*
Chu, C.C., T. Freeman, D. Nelson, T. Henneberry & E. Natwick

*Life table analysis of whitefly in cotton*
Naranjo, S.E. & P.C. Ellsworth

*Whitefly progeny production: experimental versus field data*
Gerling, D. & M. Guershon

***Developmental and Behavioral Effects of Dietary Constituents on Bemisia argentifolii***
**Jackie Blackmer**

**Section B: Viruses, Epidemiology, & Virus-Vector Interactions**
**Co-Chairs: Bob Gilbertson and Robin Huettel**

***The emergence of tomato yellow leaf curl virus in Florida***
**Polston, J.E.**

*Synergistic interactions among components of whitefly-transmitted geminiviruses*
Gilbertson, R.L.

**Section C: Chemical Control, Biopesticides, Resistance Management, and Application Methods**
**Co-Chairs: James Brazzle and Phil Stansly**

*Toxicity of insect growth regulators to whitefly populations in California, 1998*
Toscano, N.C., N.Prabhaker, G.R. Ballmer, & J.R. Brazzle

*Status of imidicloprid field performance on vegetables in Arizona*
Palumbo, J.C.

*Control of Silverleaf Whitefly and Turnip Aphid on Collards with Foliar and Soil-Applied Systemic Insecticides*
Stansly, P.A.

*Integrating the biological control agent Beauveria bassiana with chemical control for whiteflies*
James, R.R. & G.W. Elzen

*In vitro acetycholinesterase inhibition in Bemisia tabaci and its relevance to organophosphorus resistance expressed in bioassays*
Byrne, F.J. & N.C. Toscano

***Implementing a resistance management program for Bemisia argentifolii: Building the necessary bridges***
**Brazzle, J.R., N. Toscano & P. Goodell**

**Section D: Natural Enemy Ecology and Biological Control**
**Co-Chairs: James Hagler and Charles Pickett**

***Evaluating the impact of whitefly natural enemies established during the classical biological control program**
**Gould, J.**

*USDA-APHIS involvement in the classical biological control of silverleaf whitefly*
Ciomperlik, M.A. & L. Wendel

*Establishment of exotic parasitoid species of the silverleaf whitefly in Imperial Valley, California*
Roltsch, W.J., G.S. Simmons, & K.A. Hoelmer

*Update on parasite releases in the San Joaquin Valley*
Pickett, C., G.S. Simmons, B. Abel, & D. Overholt

*Lethal and sublethal impact of insecticides on whitefly predators*
Hagler, J. & S. Naranjo

*Density effects on host-parasitoid interactions*
Greensberg, S.H., W.A. Jones, & W.C. Warfield

*Impact of Beauveria bassiana on natural populations of silverleaf whitefly predators*
Ciomperlik, M.A., & T. Poprawski

*Rearing parasitoid wasps on Bemisia argentifolii cultured on artificial feeders*
Davidson, E.W. & W.A. Jones

*Survey and identification of Bemisia tabaci G. and its natural enemies*
Palaniswami, M.S.

**Section E: Host Plant Resistance, Physiological Disorders, and Host-Plant Interactions**
**Co-Chairs: Alvin Simmons and Greg Walker**

***Progress in breeding alfalfa for resistance to Silverleaf Whitefly**
**Teuber, L.R.**

*Whitefly-plant-parasitoid*
Simmons, A.M. & G. McCutcheon

*Effect of nitrogen fertility on cotton-whitefly interactions*
Bi, J.L., G.R. Ballmer, N.C. Toscano, & J. Brazzle

*Cotton Leaf Crumple resistance in Upland cotton*
Natwick, E.T.

*Behavioral and developmental effects of Dantura wrigthii trichome defenses on Bemisia*
Isaacs, R., D.N. Byrne, & S. Desai

**Section F: Integrated and Areawide Pest Management Approaches, and Crop Management Systems**

**Co-Chairs: Steve Castle and Peter Ellsworth**

*Effectiveness of living ground covers for managing spread of geminivirus in tomato by Bemisia tabaci in Costa Rica*
Hilje, L.

*Integrated management of Bemisia tabaci Gen. (Aleyrodidae) and yellow Mosaic virus in mothbean (Vigna aconitfolia) crop*
Vir, S.

*Use of Biorational and Bio-pesticides in silverleaf whitefly management in Upland Cotton in Arizona*
Akey, D.H.

*Four-year review of areawide whitefly monitoring*
Jech, L.

*An Update of the silverleaf whitefly areawide management project in California's San Joaquin Valley*
Brazzle, J.R.

*Whitefly management in Arizona cotton: A historical perspective*
Ellsworth, P.C.

***A grower initiated model for sustaining chemical efficacy across commodities**
**Palumbo, J., P.C. Ellsworth, T.J. Dennehy, & K. Umeda**

## Appendix C: List of Registered Meeting Participants


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**Appendix D. Minutes of the Silverleaf Whitefly Working Group Meeting**

## Minutes of the Silverleaf Whitefly (SLWF) Working Group Meeting

February 2, 1999

Sheraton Old Town Hotel, Suite 23

Albuquerque, NM

3:30-4:30 p.m.

### Introductory Remarks

The meeting was called to order by Robert Faust. He distributed an attendance sheet and discussed the overall objectives for the Working Group meeting and reviewed the agenda. Dr. Faust mentioned that Dr. Perring had inquired about the possibility of US Department of Agriculture funding to help support the annual progress reviews. It was estimated that about $10,000 from that source would be needed in addition to registration fees to defray costs. As Chair of the USDA Silverleaf Whitefly Research, Education and Implementation Coordinating Group, Dr. Faust stated that he would discuss the issue with the Group. Tom Perring will submit a letter/report to Dr. Faust detailing how the funds will be used. The University of California Exotic Pests Section is currently providing program planning funding by donating Lisa Arth's time. Phil Stansly recommended that the coalition also try additional outside sponsorship. Specifically, representation by the pesticide groups is lacking. Even if they don't provide funding, their input is needed. Ian Wedderspoon (Industry Representative) reported that he sent out 80 letters to industry for sponsorship and only received sponsorship from Agrevo and Valent. He solicited Bayer and Cotton Incorporated at the meeting. He said that we should solicit funds earlier so that corporate funds are not already obligated. He also stated that he would be most willing to represent the coalition and making funding requests from industry, and to let industry know that we want them there. Cindy McKenzie suggested that a breakdown of costs be generated and provided such that industry could sponsor individual breaks, mixers, etc. Peter Ellsworth noted that we also need involvement from the seed and plant breeding industry at the annual progress reviews.

### Report of Meeting Attendance

In attendance this year were 75 registrants including the working staff. Foreign visitors were from Brazil (1), Costa Rica (1), Dominican Republic (1), Guadeloupe (1), India (1), Ireland (1), Israel (1), and Pakistan (1).

### Program Brochures

Dr. Faust informed the group that he has just under 2,000 of the new brochure handed out at the meeting and titled "Management of the Silverleaf Whitefly: A Success Story in Progress" in Beltsville. Anyone interested in receiving additional copies can contact him at USDA-ARS-NPS, Bldg 005, BARC-West, Beltsville, MD 20705, ph: (301) 504-6918, fax: (301) 504-6231, email: rmf@ars.usda.gov. Ian Wedderspoon suggested that we send out copies to industry at the time he solicits sponsorship.

### Working Group Critique of Workshop and Suggestions for the PPRC

Dr. Faust stated that it would be useful to have someone give "state of the silverleaf whitefly" reports for each State in future meeting plenary sessions (or in Section F). These reports would become part of the formal program report. Peter Ellsworth indicated that cotton losses are discussed at the Beltwide Cotton Conference each year. There were outbreaks in Louisiana this year, as well as in Mississippi and Tennessee. He also suggested that the status reports should be submitted ahead of time. Steve Naranjo suggested that the information be incorporated into the beginning of the other usual reports. Loss estimates and control costs for all commodities could be included. Phil Stansly could provide information for the east coast and Ian Wedderspoon on squash, beans and tomatoes in the South. Alvin Simmons suggested that an overview be included that is not specific to any crop. Tom Henneberry suggested that the nursery and ornamental industries also could provide loss estimates for inclusion in such a report.

The group recommended that the 5-year plan tables be included as a part of the opening day packet. Also, there was trouble reading the year-2 goals table so next year each goal should be typed on a separate page (or possibly 2 to a page) in larger font. Speakers assigned to the plenary session mus be notified in writing that they are to give a presentation. At least one speaker was not aware that he was to give a presentation at the 1999 meeting.

Alvin Simmons stated that he prefers the present format of the meeting - more people stayed to the end. There was discussion as to whether the meeting could be held in

2 days and the consensus was that 2 ½ days is the minimum for the meeting. Phil Stansly recommended that the meeting next year be held in an airline hub city that is less expensive and which has direct flights. The PPRC will discuss this recommendation. Steve Naranjo noted that if in future meetings the number of submitted papers for publication should increase substantially, it might be necessary to convert some to posters after notifying the author, or alternatively, switch back to concurrent sessions. Ian Wedderspoon stated that if we go back to concurrent sessions, copies of abstracts will have to be provided ahead of time. The group also discussed the possibility of presenting the "state of the SLWF" at the end of each section.

**International Activities**

A number of international activities on SLWF were briefly noted: A meeting in the UK in 1999; the Whitefly IPM Initiative between Africa/Central American countries (CIAT); International Congress of Entomology, Brazil, July 22-29, 2000; XIVth International Plant Protection Congress, July 25-30, 1999, Israel; VII Plant Virus Epidemiology Symposium, April 11- 16, 1999, Spain.

**Other Business**

Richard Mayer asked if it would be possible to put the entire annual progress report, or at least the abstracts, on the Internet. It was determined that this could not be accomplished now, but might be considered for the future. A deadline of February 12, 1999, was set for receipt of all corrected and/or additional abstracts. All technology transfer/progress review summaries and year 2 tables for the 1999 Progress Review and Technology Transfer Report are due by February 26, 1999.

Information should be sent to:

Marla Lawrence

USDA-ARS WCRL

4135 E. Broadway Rd.

Phoenix, AZ 85040-8803

*thenneb@ix.netcom.com*

It was requested that the information listed above be transmitted either on disk with a hard copy or via-e-mail with a hard copy in Word97 or Wordperfect 6.0.

The minutes for the Working Group meeting will be transcribed by Marla Lawrence and then sent to Dr. Faust for review. The minutes will be included as an Appendix in the 1999 SLWF Progress Review and Technology Transfer Report.

Dr. Faust adjourned the Working Group meeting at approximately 4:30 p.m.

Respectfully submitted,

Marla Lawrence

Secretary

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Enclosures:

- SLWF Working Group Meeting Attendees
- SLWF Working Group Agenda

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**Silverleaf Whitefly Working Group Meeting**

February 2, 1999

Albuquerque, New Mexico

3:30 - 4:30 p.m.

Robert M. Faust, ARS-NPS, Presiding

**AGENDA**

| | | |
|---|---|---|
| C | Introductory Remarks/Old Business | R. Faust |
| C | Report of Meeting Attendance | L. Arth |
| C | Program Brochures | R. Faust |
| C | Working Group Critique of Workshop & Suggestions for the PPRC | Group |
| C | International Activities | Group |
| C | 1999 Program Review Report | L. Arth/T. Perring |
| C | Other Items | Group |
| C | Adjourn | |

**Appendix E. Minutes of the Program Planning Review Committee**

Minutes

PPRC Meeting

Sheraton Old Town Hotel, Suite 23

1/31/99

Meeting was chaired by Tom Perring and Lisa Arth. PPRC members in attendance were:

| | | | |
|---|---|---|---|
| Lisa Arth | James Brazzle | Steve Castle | Peter Ellsworth |
| Robert Faust | Bob Gilbertson | Robin Huettel | Rufus Isaacs |
| Walker Jones | Marla Lawrence | Steve Naranjo | Tom Perring |
| Charlie Pickett | Alvin Simmons | Phil Stansly | |

Lisa Arth discussed the general overview of the program and reminded Section Co-chairs of their assignments during the meeting which included: 1) keeping the scheduled talks on time, 2) leading discussions, and 3) updating year 2 tables during the progress review.

Lisa reminded Section Co-chairs that after the meeting they must submit section summaries with technology transfer and completed year 2 tables to Marla Lawrence.

Marla Lawrence will send co-chairs all copies of abstracts by February 16th. Lisa will follow-up this information by e-mail.

Deadlines for abstracts submission or changes will be February 12th and Section Chair information is due to Marla Lawrence by February 26th.

Lisa asked current section chairs to be prepared to recommend co-chairs to the Program Planning Committee.

The next PPRC meeting will be held after the Technical Working Group Meeting. Co-chairs were asked to be thinking about next year’s meeting dates and location.

Minutes

PPRC Meeting

Sheraton Old Town Hotel, Suite 23

2/2/99

Meeting was chaired by Lisa Arth and Tom Perring. Members in attendance were:

| | | | |
|---|---|---|---|
| Lisa Arth | James Brazzle | Steve Castle | Peter Ellsworth |
| Robert Faust | Bob Gilbertson | James Hagler | Tom Henneberry |
| Robin Huettel | Rufus Isaacs | Marla Lawrence | Richard Mayer |
| Cindy McKenzie | Steve Naranjo | Tom Perring | Charlie Pickett |
| Alvin Simmons | Phil Stansly | Greg Walker | Ian Wedderspoon |
| Lloyd Wendel | | | |

Lisa Arth asked that the committee review the recommendations about dates, location and structure of the next progress review.

Tom Perring discussed several possible meeting sites based on the technical working group's recommendations. The group decided on San Diego, CA during the 1st week in February.

The meeting format will be Sunday through Wednesday with an afternoon start. The structure will be plenary, if possible, depending on number of submissions. This will be determined by the Committee at such time as necessary. It will remain at 2 ½ days and the progress review will continue to be held at the end of the meeting. Section A will continue to be on the last day.

Lisa Arth requested the section chairs submit replacements for the 1999 meeting:

| | | |
|---|---|---|
| Section A | Rufus Isaacs | Mike Salvucci |
| Section B | Robin Huettel | Bob Gilbertson |
| Section C | James Brazzle | tbd |
| Section D | James Hagler | Matt Ciomperlik |
| Section E | Greg Walker | Cindy McKenzie |
| Section F | Steve Castle | Luko Hilje |

The Section Chairs need to insure that final replacements are submitted to Lisa Arth no later than 26 February 1999.

A reminder of the deadlines:

| | |
|---|---|
| Abstracts | 12 February |
| Year 2 Tables | 26 February |
| Section summary/technology transfer | 26 February |
| Revisions to 5-year table | 26 February |

Dr. Henneberry requested that any revisions to the 5-year tables be footnoted to indicate when the changes were made to avoid confusion later on.

## Appendix F: 5-Year National Research and Action Plan Priority Tables, Research Approaches, and Yearly Goals (1997–2001)

**Five-Year National Research and Action Plan Priority Tables, Research Needs, and Yearly Goals (1997–2001)**

**Table A. Biology, Ecology, and Population Dynamics**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Determine life cycle vulnerabilities (life tables)a, population development and natural mortality factors, natural enemies on major crops, urban plantings, weeds and predict overwintering potential.** | Whitefly and natural enemy sampling in cultivated crops, urban planting and weed hosts. | Determine potential of intercrop weed host & urban planting, movement of whiteflies and natural enemies. | Identify potential low population manipulation on vital host links for survival. | Initiate studies to manipulate host sequences to determine potential influence on whitefly population. | Continue 4 and finalize analysis of the potential of habitat modification as a management tool. |
| **Develop sampling methodology, action andb,c economic thresholds for all major crops. Sampling methods and thresholds modified in light of natural enemy levels and existing management strategies.** | Initiate whitefly to identify spatial and temporal distributions in major cultivated crops. | Analysis and identification of needed additional sampling research to develop appropriate sampling protocol. | Validate and refine sampling methods. | Implement sampling protocols through cooperative extension outlets and other technology transfer methods. | Finalization, implementation and use in IPM systems. |
| **Develop population models to describe and predict whitefly population growth and spatial and temporal distribution. Develop simple day-degree sub-models for estimating phenology and temporal patterns of whitefly, natural enemies and host crops.** | Summarize whitefly biology, ecology and plant phenology to identify whitefly host plant interfaces. | Begin model development to include all biological and plant phenology data in simulation development. | Provide model simulation of whitefly populations and multiple cropping systems. | Identify weak points and needed information to improve model simulations. | Validate and expand effort to provide predictive models capabilities for whitefly population development and crop interfaces. |
| **Develop sampling methods for quality of cotton lint, vegetables and other commodities.** | Initiate sampling of seed cotton in the field during the season, at harvest, after picking, moduling and ginning. | Based on 1, expand and repeat sampling protocols as described. | Develop sampling protocol for field and harvest and processing sampling and determine interrelationships. | Extend sampling protocols to textile mill and verify field findings in relation to mill problems. | Modify, refine and complete sticky cotton sampling protocols from the field to the mill. |
| **Quantify whitefly and natural enemy dispersals and contribution to population dynamics.** | Review and analyze existing knowledge of whitefly dispersal. | Validate times of whitefly dispersal, environmental factors and identify modifying factors. | Determine proportion of whitefly population that are migratory and their reproductive potential. | Quantify the role of dispersal in population dynamics on different crop systems. | Formulate theory for manipulating and/or using dispersal as a tool in IPM. |

**Table A. Biology, Ecology, and Population Dynamics**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Define mating behavior, reproductive isolation, species, biotypes.** | Initiate studies on mating, oviposition and other behavior. | Define interspecies interbiotype mating interactions. | Define factors involved in mating, cues, feedback mechanisms, etc. | Develop potential methods of utilizing behavioral information in management strategies. | Review, summarize and propose additional needed research. |
| **Validate *Bemisia* taxa morphology, genetic, biochemical, and biology characteristics.** | Continue examination of *Bemisia* sp. for distinct morphological character differences. | Develop genetic molecular level and acceptable species level separation. | Discuss results, plan additional research, arrive at a consensus decision. | Publish verification of new species or other appropriate taxa. | --------------------- |
| **Define role of endosymbionts in metabolism, host adaptation, nutrition and survival.** | Identify endosymbionts in whitefly. | Determine role of endosymbionts in whitefly biological functioning. | Determine potential for manipulating, interfering with or inhibiting endosymbiont function. | Determine associated enzymes and/or other endosymbionts and whitefly relationships. | Summarize and implement findings with suggestion for additional research. |
| **Characterize nutrient uptake and metabolism.** | Identify the major carbohydrates, amino acids and other nutrients essentail for whitefly growth and development. | Determine the biochemical pathways for metabolism of compounds essential for whitefly development. | Determine the physical and biochemical processes involved in uptake of carbohydrates, amino acids and other essential nutrients. | Determine the potential for blocking key steps in nutrient uptake and/or metabolism. | Implement findings by developing inhibitors of nutrient uptake and/or metabolism. |
| **Develop whitefly artificial diets and natural enemy mass-rearing.** | Identify whitefly nutritional components in plant tissue. | Develop whitefly artificial feeding systems. | Conduct addition, deletion studies to identify essential nutritional needs. | Evaluate developed diets on whitefly fecundity/longevity biology, behavioral characteristics. | Develop whitefly rearing system and adapt for production of natural enemies. |

a Natural enemy research complements from Section D, see Table D.
b Action and economic thresholds also apply in Section C, see Table C.
c Sampling technology applicable to all other sections, see Tables B to F.

**Table B. Viruses, Epidemiology, and Virus-Vector Interactions**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Identification and characterization of new or emerging whitefly-transmitted viruses and strains** | Monitor crops for presence of whitefly-transmitted diseases, and determine relative disease incidence. Begin virus identification and strain differentiation. | Virus identification and characterization. Develop methods for identifying causal agents and for tracking viruses and strains using molecular methods. | Continue etiological studies and virus characterization. Apply molecular diagnostics to virus identification and evaluation of disease incidence and virus distribution. | Continue etiological studies and virus characterization efforts. Apply molecular diagnostics to virus identification and evaluation of disease incidence and virus distribution. | Summarize and review results. Determine areas of new research. |
| **Molecular epidemiology: identification of economic viruses, host plants, and reservoirs, and determination of geographic distribution of viruses.** | Monitor and identify host plants, virus reservoirs in affected areas. Linkages to diagnostic methods for virus ID and tracking. | Continue field studies. Determine economic input of diseases on crop production and associated losses. | Establish geographic distribution of viruses and identify sources of inoculum. Assess role of alternative host virus reservoirs on spread of diseases. | Identify and characterize virus involvement in disease establishment and spread. Assess potential methods of reducing virus reservoirs as a method of reducing disease. | Review and make recommendations for further research and potential implementation of results. |
| **Virus-vector interactions, factors affecting virus transmission, and basis for virus-vector specificity; determination of endosymbiont involvement in whitefly-mediated transmission** | Initiate studies on virus-vector interactions and on basis for the specificity of whitefly-mediated geminivirus transmission. | Determine specific cellular and molecular factors involved in virus transmission. Study role of endosymbionts in virus acquisition and transmission. | Continue studies in progress to determine specific factors involved in virus transmission, and the role of endosymbionts in virus acquisition and transmission. | Continue virus-vector interactions studies toward the development of approaches for disease control. | Summarize findings and suggest new research needs; implementation of existing knowledge. |

**Table B. Viruses, Epidemiology, and Virus-Vector Interactions**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Strategies to reduce virus spread by management of cropping systems, reduced transmission frequencies, and other potentially effective approaches.** | Develop approaches to managing cropping systems to reduce vector densities to decrease transmission frequency and inoculum sources, taking into account weed and crop reservoirs in disease incidence and distribution. | Continue studies of management approaches for disease abatement. Interdisciplinary studies in conjunction with whitefly control methods in Sections B and C. | Continue studies of management approaches for disease abatement. Focus on interdisciplinary studies in conjunction with whitefly control methods in Sections B and C. | Evaluate strategies for crop management and impact on disease epidemiology. | Evaluate approaches and identify areas of future research for disease control by management of cropping systems. Linkages with IPM approaches. |
| **Control of virus diseases: development of virus resistant germplasm through conventional and engineered/molecular approaches. Define prospective strategies for selecting candidate viruses, identifying specific virus diseases to target, and prioritize specific crops and cultivars for protection approaches.** | Define strategies for resistance efforts. Identify target viruses. Identify germplasm with virus resistance. Initiate efforts toward defining prospective engineered resistance strategies. Identify candidate crops and recipient cultivars. | Continue to define suitable strategies for determining target viruses. Isolate and characterize virus-resistant germplasm. Continue work toward engineered resistance in target crops and selected viruses. | Further identification of resistant germplasm and develop new methods of incorporating resistance into crop plants. Evaluate resistance strategies with respect to broad spectrum or virus-specific protection. | Continue development of resistant varieties. Evaluate resistance strategies with respect to broad spectrum or virus-specific protection. Define mechanisms of resistance. | Evaluate resistant plants in greenhouse and field experimentation, and identify additional research. Molecular-based monitoring of transgenes in environment. |
| **Pursue specific genetic and biological basis for variability in whitefly biotypes, strains, and species; determine impact of different genotypes/phenotypes on whitefly-mediated transmission and on the epidemiology of virus diseases.** | Identify differences in species, strains and biotypes with respect to transmission, host range, mating compatibilities, molecular variability, and map the biogeographic distribution of distinct types within the B. *tabaci* species complex. | Continue to study differences in species/ strains/biotypes with respect to transmission, host range, mating compatibilities, molecular variability. Determine molecular basis of observed variability in biological, molecular, & genetic terms. Infer molecular phylogenies from molecular markers. | Continue with work from previous years. Study impact of biotypes, strains, and species differences in the disease spread, crop damage, and specific control measures to reduce whitefly vector populations. Linkages with biological and chemical control sections. | Identify potential factors related to specific genetic and biological variability that may be manipulated to reduce disease spread. Develop molecular approaches to track biotypes, strains, and species relative to disease spread, based on differential molecular markers. | Summarize results, identify new research needs and make recommendations for implementation or expansion of research. |

**Table C. Chemical Control, Biopesticides , Resistance Management, and Application Methods**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Improve insecticide efficacy:** | | | | | |
| ! **Develop, test, and assist in the registration of insecticides, biorationals, and natural products.** | Develop new chemistries and natural products. Develop improved techniques for evaluating efficacy of insecticides. Support registration of desirable new products by providing information to regulatory agencies. | Same as Year 1. Determine new modes of action of effective materials. Elucidate biochemical pathways of synthesis and degradation of natural products. | Same as Year 2. Evaluate the potential for transforming plants with natural product genes. | Same as Year 3. | Same as Year 4. |
| ! **Develop improved methods of application including formulation and delivery of materials to improve control.** | Develop spray systems for better underleaf coverage. Evaluate rates, timing, placement in relation to efficacy. Consider formulation, UV protectants, and other means to improve efficacy. Develop improved methods to evaluate application efficacy. Field test under commercial conditions for technology transfer. | Same as Year 1. | Same as Year 2. | Same as Year 3. | Same as Year 4. |

**Conserve insecticide efficacy:**

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| ! **Relate action thresholds to insecticide usage patterns.** | Refine action thresholds based on insecticide efficacy and input from other control strategies. | Same as Year 1. | Same as Year 2. | Same as Year 3. | Same as Year 4. Summarize and recommend in IPM systems. |
| ! **Elucidate the role of genetic, biochemical and ecological factors leading to insecticide resistance.** | Establish whitefly strains resistant and susceptible to various classes of insecticide. Conduct studies to determine the genetics and biochemistry of resistance and cross resistance to different classes of insecticide. | Same as Year 1. Evaluate the role of refuge habitats (weeds, tolerant crops, urban areas) to assure input of susceptible genes in whitefly population. | Conduct studies to determine the genetics and biochemistry of resistance and cross resistance to different classes of insecticide. Evaluate the role of refuge habitats (weeds, tolerant crops, urban areas) to assure input of susceptible genes in whitefly population. Evaluate the influence of host plant on susceptibility to insecticides. | Same as Year 3. | Same as Year 4. |

**Improve insecticide efficacy:**

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| **Improve techniques for monitoring resistance.** | Establish baseline data on toxogenic responses of whitefly populations to new insecticides. | Same as Year 1. Expand comparative studies of resistance levels in diverse agro-ecosystems. Evaluate relationship between monitoring results and field efficacy. | Same as Year 2. Summarize, analyze, and produce standardized comparable monitoring systems. | Same as Year 3. Develop standard systems for general use including user friendly techniques to assist growers and extension agents to evaluate susceptibility of whitefly populations to commonly used insecticides. | Same as Year 4. |

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| **Develop, evaluate and refine resistance management systems** | Evaluate the effects of mixtures and rotations of new and old chemistries to mitigate selection for resistance. | Same as Year 1. Develop methods to evaluate and augment the beneficial influence of refuges as sources of susceptible genes to the population pool. | Same as Year 2. Develop criteria for integration of successful strategies in agricultural systems. Field test resistance management systems as long range components of successful IPM. | Same as Year 3. | Same as Year 4. Technology transfer. |
| **Integrate chemical control with other tactics.** | Evaluate selectivity of synthetic insecticides and natural products to key whitefly natural enemies. | Same as Year 1. Test compatibility of biological control with selective synthetic or natural product insecticides as required. | Same as Year 2. Integrate systems with host plant resistance and cultural controls. | Test compatibility of biological control with selective synthetic or natural product insecticides as required. Integrate systems with host plant resistance and cultural controls. | Integrate systems with host plant resistance and cultural controls. Summarization and technology transfer. |

a See Table A for complementary research on thresholds.
a See Table B for complementary research on virus/vector interactions.
a See Table D for complementary research on biological control.
b See Tables E and F for complementary research on systems management.

**Table D. Natural Enemy Ecology and Biological Control**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Natural control and conservation:** | | | | | |
| ! **Develop natural enemy conservation practices to reduce mortality to indigenous and introduced natural enemies.** | Conduct life table analyses of indigenous and introduced natural enemies to identify key mortality factors of natural enemy populations. | Identify the spatial scale upon which the key mortality agents are acting. | Conduct manipulative experiments to evaluate the impact of each natural enemy mortality agent on whitefly suppression. | Conduct a feasibility study and economic assessment of altered crop management practices that may enhance the impact of indigenous natural enemies. | Develop and evaluate area wide programs to facilitate full implementation. |
| ! **Evaluate potential of alternate plants it act as in-field refuges or insectaries for natural enemies.** | Identify potential plants for natural enemy population development and assess risks of these plants to foster additional pest problems. | Determine refugia plant phenology in relation to cultivated crop phenology. | Conduct field tests to assess whether refuges act of natural enemy and whitefly sinks or sources to adjacent cropping systems. | Conduct field tests to evaluate spacing of refuges necessary to achieve satisfactory whitefly suppression. | Conduct a feasibility study and economic assessment of alternate plantings in terms of an entire crop management program. |
| ! **Assess cues used by natural enemies to locate whitefly to identify potential methods for enhancing natural enemy activity.** | Conduct laboratory tests to identify cues used by natural enemies to locate and attack whitefly. | Determine potential methods for manipulating cues as part of a whitefly management program. | Conduct small scale trials to enhance whitefly suppression by manipulating natural enemy location and attack of whitefly. | Conduct large scale field trials and evaluate product development for commercial investment as necessary. | Transfer technology (as needed) to commercial interests for full implementation. |
| **Augmentation of natural enemies:** | | | | | |
| ! **Develop natural enemy mass-rearing systems.** | Identify natural enemies with the highest potential for controlling whitefly in key cropping systems. | Determine nutritional, physiological, and ecological requirements for mass-rearing. | Develop rearing systems on selected hosts and on artificial diets. Determine economic feasibility of the procedure. | Evaluate rearing system effects on natural enemy life history characteristics, behavior, and ability to suppress whitefly populations. | Facilitate transfer of mass-rearing technology to commercial interests as necessary. |

**Importation biological control:**

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| ! **Develop release technologies to maximize the effectiveness of mass-reared natural enemies in the field.** | Identify natural enemies with the highest potential for controlling whitefly in key cropping systems and that may be economically mass produced. | Evaluate the fate of natural enemy life stages under field conditions to identify the appropriate developmental stage to be released. | Develop necessary technology for release of the appropriate natural enemy life stage. | Evaluate release technology effects on natural enemy life history characteristics, behavior, and ability to suppress whitefly populations. | Facilitate transfer of mass-rearing technology to commercial interests as necessary. |
| ! **Evaluate augmentative parasitoid, predator, or pathogen releases.** | Initiate studies on natural enemy augmentation with identified high potential natural enemies. | Conduct releases on selected crop systems at various rates of release. | Identify optimal release strategies for key cropping systems. | Continue evaluation of releases, determine need for additional releases. Compare results in different cropping systems and environments. | Analyze information and make recommendation regarding need for expansion of the approach. |
| ! **Evaluate the ability of exotic natural enemies to suppress whitefly populations under field conditions.** | Identify sites suitable for the release and subsequent evaluation of each candidate natural enemy. Conduct inoculative releases of natural enemies. | Evaluate establishment of exotic natural enemies within target release area. Determine if additional releases are necessary. | Assess spread of established natural enemies and their ability to suppress whitefly populations. | Continue to assess the spread of established natural enemies and their ability to suppress whitefly populations. Evaluate program progress and determine if additional strategies are necessary. | Complete program analysis. Publish program assessment and conduct an economic assessment. |

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| ! **Clarify systematics of predators, parasitoids and pathogens.** | Conduct taxonomic studies of species within targeted release sites. Verify taxonomic purity of mass-reared natural enemies. Complete taxonomic work on poorly characterized but important groups. Assist in determining most suitable natural enemies for release through biogeographical analysis | Provide taxonomic support for importation and mass-rearing programs. Publish keys to assist in species identifications. | Provide taxonomic support for importation and mass-rearing programs. | Provide taxonomic support for importation and mass-rearing programs. | Provide taxonomic support for importation and mass-rearing programs. |
| **Systematics, ecology, and population dynamics of natural enemies[b]:** | | | | | |
| ! **Determine *Bemisia* - natural enemy-host plant (Tritrophic) interactions.** | Initiate studies to identify mechanisms involved in *Bemisia* - and natural enemy plant attraction. | Study plant characteristics mediating whitefly population densities. | Study compatibility of characteristics of plant traits mediating whitefly populations with the abilities of natural enemies to suppress whitefly populations. | Assess the implementability of favorable tritrophic interactions within the context of an whitefly management program. | Implement and evaluate large scale crop management programs for suppression of whitefly populations. |
| ! **Identify the attributes of natural enemy biology and population level interactions to explain biological control successes and failures.** | Assess the value of the *Bemisia* biological control research to evaluate key issues to the science of biological control. | In conjunction with field evaluations, validate predictions made by behavioral and population models important to biological control. | Assess deviations between theoretical predictions and field data. | Evaluate behavioral or population level parameters that may explain observed deviations. | Quantify the impact of basic research on the development of feasible biological control programs for *Bemisia* and the advancement of the field as a science. |

a See Table C for complementary research.
b See Table A for complementary research.

**Table E. Host Plant Resistance, Physiological Disorders, and Host Plant Interactions**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Characterize resistance mechanisms and identify chemical/morphological components, and study effects of insect adaptation.** | Identify potential sources of germplasm for disease, plant disorders and whitefly resistance.[a] | Determine physiological and/or morphological basis for resistance, & effects of host-plant history and insect adaptation on plant resistance to whiteflies. Continue to identify resistant germplasm. | Elucidate biochemical and molecular basis for resistance. Continue to identify resistant germplasm. | Determine potential for transfer of resistance traits. | Evaluate potential for incorporating Bemisia, plant disorder and disease resistance into acceptable plant type. |
| **Develop molecular level techniques to produce resistant germplasm.** | Identify physiological processes of whiteflies to target for inhibition. | Identify natural products for inhibiting processes. | Isolate the relevant biosynthetic enzymes that encode for natural products inhibiting processes. | Insert genes into plants via plant transformation. [b] | Evaluate potential of newly transformed germplasm. |
| **Incorporate resistance traits into commercial genotypes.** | Identify and isolate genetic sources of resistance for transformation and/or breeding. | Insert genes into plants[b] via plant transformation. | Evaluate potential of newly transformed germplasm. | Continue to refine resistance factors to improve resistance in newly transformed germplasm. | Incorporate other desirable plant characteristics for crop production. |
| **Determine influence of host plant morphology, physiology and phenology on feeding behavior and competition.[c]** | Characterize nutritional and other preference properties of various host plants. | Determine the biochemical mechanism regulating adaptation to host plants. | Determine changes in whitefly gene expression in response to host manipulation. | Relate changes in gene expression to whitefly physiology. | Summarize and disseminate results. |
| **Define whitefly feeding and oviposition behavior and investigate approaches for interrupting whitefly feeding and digestion.[d]** | Investigate approaches for interruption of feeding, assimilation, development and reproduction. | Identify physiological and morphological mechanisms regulating processes. | Determine biochemical and molecular basis for inhibiting processes. | Determine potential for transfer of resistance traits. | Insert genes into plants[a] via plant transformation. |

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| **Study whitefly toxicogenic plant reactions.** | Determine effects of whitefly feeding on host plant physiology, morphology and anatomy. | Determine biochemical basis for physiological response of plant. | Elucidate changes in plant gene expression. | Identify resistance germplasm. | Evaluate potential for transferring new germplasm. |

a See Table B for additional plant disease resistance research.
b Progress at this point may extend to several year research.
c See Section A.
d See Section A, approach #9.

**Table F. Integrated and Areawide Pest Management Approaches and Crop Management Systems**

| Approaches/Goals | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| **Development:** | | | | | |
| **Study whitefly-crop interactionsb as cultural components that affect population dynamics, e.g., water, nutrients, plant population, planting/ termination/harvest dates, other farm practices, intercrop relationships.** | Identify potential beneficial or exacerbating farm practices or inputs for testing. | Determine nature and character of relationship between interaction and whitefly population dynamics. | Identify mechanisms governing relationship and alter or manipulate factors that suppress whitefly dynamics. | Refine system, add other compatible components, evaluate economic impact; conduct field testing and evaluations. | Conduct economic analyses and determine next level of IPM/ICM systems evaluation. Develop recommendations of best management practices. |
| **Develop behavioral barriers[b] to whitefly colonization and population development, e.g., mulches, trap crops, intercropping, row covers, etc.** | Review potential behavioral disrupters and evaluate as potential IPM components. | Conduct field-level trials; quantify impact to crop and whitefly dynamics | Apply promising technologies to high-value crop systems; field test and evaluate. | Refine system, add other components, and conduct economic feasibility analyses. | Summarize and evaluate results; prepare crop systems-specific recommendations. |
| **Integration:** | | | | | |
| **Develop Integrated Pest Managementc systems using dual or multiple control tactics, e.g., cultural, biological, chemical, host plant resistance, etc.** | Identify candidate dual or multiple control tactic systems, e.g., IGRs and natural enemy conservation. | Initiate field testing of candidate systems. | Continue field testing & evaluate feasibility of large scale testing; add components as necessary. | Initiate large-scale experiments; incorporate economic evaluation. | Evaluate multiple component system as potential deliverable; prepare recommendations |
| **Integrate sampling with other key components of IPM systems, e.g., thresholds, economics, decision-making, biological control, etc.** | Develop or modify sampling systems for new crops; integrate with thresholds and decision-making. | Establish practical utility of system through economic analyses; field efficiencies and costs. | Integrate additional control components into sampling, threshold & decision-making systems | Evaluate in whole field systems. Identify weaknesses; target improvements. | Evaluate redesigned decision systems; continue field testing and economic analyses. |

**Delivery and Implementation:**

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|---|---|---|---|---|---|
| **Elevate single field/farm practices to areawide community-based contexts; develop methodology for installing and evaluating areawide control technologies and their impact.** | Identify agricultural communities amenable to areawide management; conduct thorough pre-implementation evaluation. | Install control technologies into community; develop systems for evaluation. | Identify additional IPM/ICM compatible components. Re-assess and adapt program. Conduct areawide economic analyses. | Formulate clientele surveys; develop & begin to implement protocols for evaluating areawide technologies. | Refine, reevaluate and identify weaknesses. Formulate recommendations for future areawide management systems. Conduct surveys. |
| **Implement and deliver Integrated Pest Management and Integrated Crop Management systems or system components to clientele.** | Develop and distribute provisional IPM & ICM recommendations. | Conduct whole farm/operation demonstrations of IPM systems. | Expand sites of testing with grower cooperators; conduct validation studies. | Incorporate new information and economics into recommendations. | Validate new components; finalize recommendations; expand to new crops. |

a See Tables A to E for additional complementary research.

[b] See Table A for additional complementary research.

[c] See Table E for additional complementary research.