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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Issued June 1999

Table A. Biology, Ecology, and Population Dynamics.

Research Approaches	Year 1 Goals Statement	Progress Achieved Yes	Progress Achieved 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	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.	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	Progress Achieved 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	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	Progress Achieved 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.

Table B. Viruses, Epidemiology and Virus Vector Interactions.

Research Approaches	Year 1 Goals Statement	Progress Achieved Yes	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		Significance
		Yes	No	
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. 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. 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. 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. 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	

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

Research Approaches[a]	Year 1 Goals Statement	Progress Achieved Yes	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	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	Progress Achieved 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	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	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.

Table D. Natural Enemy Ecology and Biocontrol.

Research Approaches[a]	Year 1 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.	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 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	Progress Achieved 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.

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

Research Approaches[a]	Year 1 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.	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: C row covers and screens as physical barriers, C mulches and oils as behavioral barriers, 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: C Insect Growth Regulators & biological control in cotton (conservation) C imidacloprid & other chemical control tactics & various forms of biological control, especially in vegetables 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: C *Bemisia* distributions have been examined in tomato, C new binomial sampling system for large nymphs in cotton, & integration with thresholds for IGR decisions 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: C areas dominated by cotton were identified in AZ & CA for implementation of cooperative programs. C areas of melon and vegetable production were identified in TX for potential area-wide programs. 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: C IPM recommendations were distributed AZ, CA, Mexico & FL; bilateral discussions between Brazil & U.S. took place. 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	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.	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.