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National Program 308: Methyl Bromide Alternatives

Accomplishment Report 2000-2005

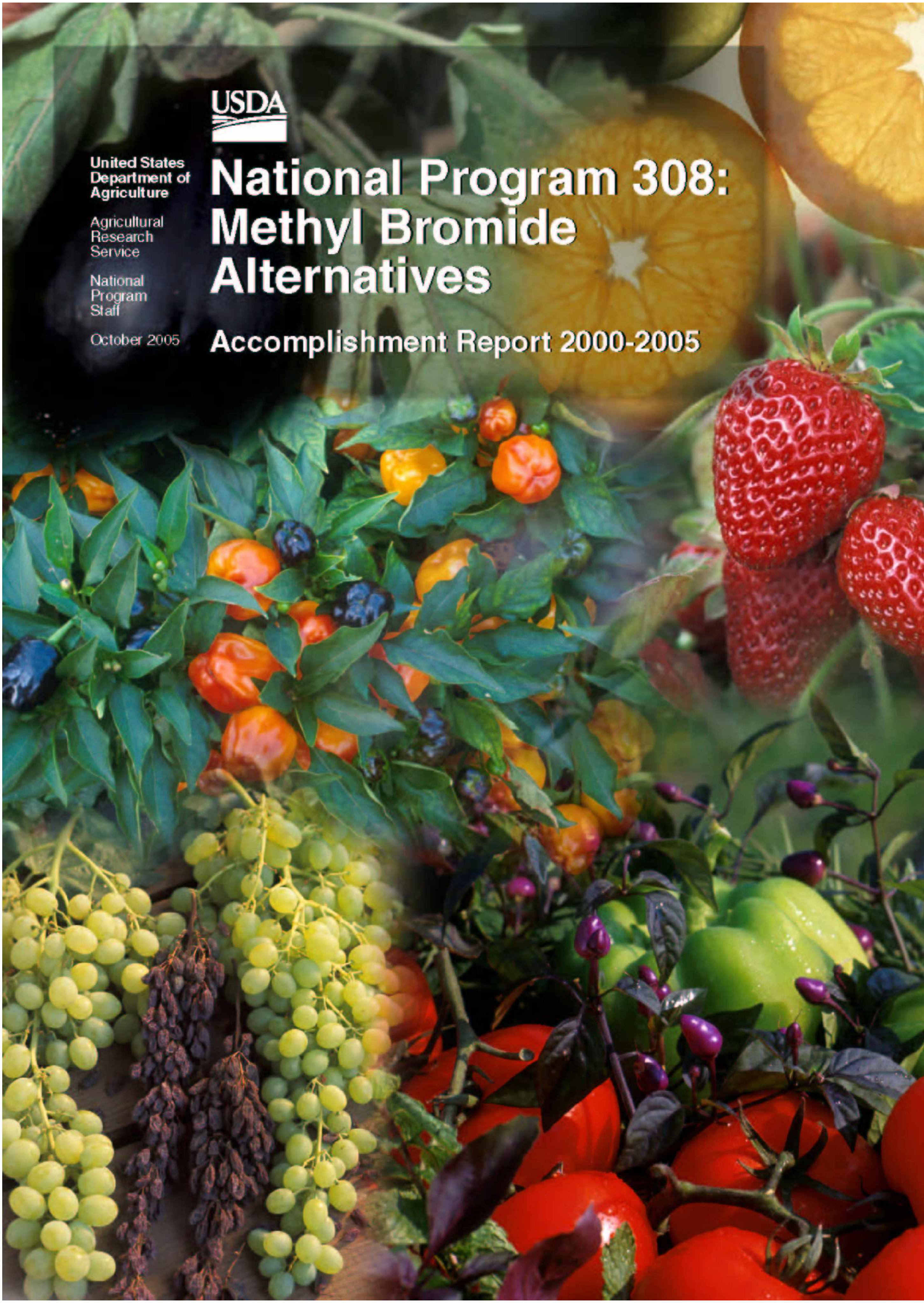

Table of Contents

BACKGROUND AND GENERAL INFORMATION

In 1992, methyl bromide was identified as a chemical that contributes to the depletion of the ozone layer. This put methyl bromide under the jurisdiction of the U.S. Clean Air Act, which requires any substance identified as ozone depleting to be withdrawn from production, importation, and use in the United States by 2000. Since the United States is a Party to the Montreal Protocol, which banned production and importation of methyl bromide for developed countries beginning in 2005, the Clean Air Act was later amended to conform to the Montreal Protocol. Because methyl bromide is critically important to certain segments of U.S. agriculture, the U.S. Department of Agriculture (USDA) responded by vigorously promoting research to find alternatives to this highly effective fumigant that is used to control insects, nematodes, weeds, and pathogens for pre-plant soil fumigation, post-harvest protection, and quarantine treatments.

The Agricultural Research Service (ARS) brought together agricultural and forestry leaders from private industry, academia, and state and Federal government to assess the problem, formulate priorities, and implement research directed at providing solutions. These sectors have established and maintained working relationships throughout the research for alternatives. ARS has identified all in-house research projects related to methyl bromide alternatives and increased funding over a number of budget cycles to allow expansion of efforts to find pest management solutions. In 1998, when ARS research was organized into National Programs (NP), one of these, NP 308 (Methyl Bromide Alternatives) was created to encompass the research. The vision of this program is to find effective, economical, and practical alternatives to methyl bromide. In keeping with the vision, the Program's mission is to develop environmentally compatible and economically feasible alternatives to the use of methyl bromide as a soil and post-harvest commodity treatment.

PLANNING AND COORDINATION FOR NP 308

ARS scientists and administrators met with customers, stakeholders, and partners in two workshops held in Orlando, Florida, in December 1998, and in Monterey, California, in April, 1999. The participants at these meetings reviewed current research and established future priorities. The input from these meetings was used to develop the current Action Plan, and the research accomplishments presented in this report address the priorities established following these meetings.

Once the Action Plan was completed, specific research Project Plans were written by individual scientists or teams of scientists. Project Plans include statements of anticipated products or information to be generated by the Project, how the projects contributed to solving issues associated with the loss of methyl bromide, and timelines and milestones for measuring progress towards the Project's goals. The project peer reviews were handled by the ARS Office of Scientific Quality Review in August 2002. Project Plans were revised in response to review panel recommendations, then implemented. Progress towards achieving the Action Plan goals is now being assessed by an external assessment panel. This assessment is in preparation for the beginning of the next 5-year National Program cycle.

The critical nature of finding replacements for methyl bromide has made NP 308 a highly visible program. Information on research progress is constantly being sought by the USDA Secretary's Office, as well as the U.S. Environmental Protection Agency (USEPA) and the State Department. Coordination with research programs outside ARS that are searching for methyl bromide alternatives is also essential. Such coordination is the task of National Program Leaders who comprise the NP 308 Leadership Team. ARS National Program Staff and scientists have many opportunities to meet with other scientists, grower groups, regulators, and additional interests to discuss research progress. One of the most visible meetings with large participation is the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions, where research presentations and discussions afford an opportunity to share information and determine future directions in methyl bromide alternative research.

HOW THIS REPORT WAS CONSTRUCTED AND WHAT IT REFLECTS

In this Report, information about NP 308 achievements and impact is organized according to two NP Components and their constituent Problem Areas described in the NP Action Plan. Because each component was developed independently of the other, the formats of these two sections differ somewhat. Under each Problem Area the **outcomes, goals and commitments** are specified. These are followed by **selected accomplishments** achieved during the last 5 years and by the **impact** of those achievements on solving the problems and meeting the high-priority needs identified by customer/stakeholders in the NP 308 Action Plan. **Appendix I** for each component provides the selected supporting information and documentation for accomplishments by Research Component and Problem Area, and **Appendix II** for each component lists major cooperators and contributors.

For the most part, the content of this report is derived from responses to a recent survey of the scientists assigned to NP 308, as well as scientists in other NPs whose projects are coded to methyl bromide alternatives. These scientists were asked to summarize their projects' significant accomplishments during the last 5 years, the impact of these, and key references documenting accomplishments. Consequently, this report does not cover all accomplishments of each research project, but rather only those selected by the ARS scientists polled and the ARS scientists and National Program Leaders who authored this report. As a result, the scope of this report encompasses a subset of the total spectrum of NP 308 accomplishments, chosen to illustrate and exemplify the total progress and achievements of this NP and related projects. The titles of the individual projects are listed in **Appendix III – Research Projects**. This appendix is organized according to the geographical location of the research unit. Note that some of these projects began more recently than 2000, when the first NP 308 program cycle began.

Research Component I: Preplant Soil Fumigation Alternatives

The loss of methyl bromide for soil fumigation will result in serious disease, pest, and weed problems. These problems will likely be highly variable and will depend on crop, soil type, environment, and cropping systems. Therefore, separate research efforts will be required to develop multiple management strategies. Approaches will include host plant resistance, biological control, cultural practice modifications, alternative chemicals and combinations of the above.

Problem Area 1a – Chemical Controls

Outcomes, Goals and Commitments: The bulk of the research program on chemical alternatives to methyl bromide is concentrated on chemicals that have current EPA registrations as pesticides. Most of these chemicals have been registered for many years and the research effort is devoted to research to make them more efficacious, such as new application technology, or to find ways to extend their use into the methyl bromide area. Critical goals for this problem area were to develop cost-effective alternative chemicals for control of soilborne pests in soil and vegetable nurseries and production fields and to develop alternative application methods for Telone that minimize safety and environmental problems. Alternative chemicals, or combinations of chemicals, have been identified and field-tested. Field-scale tests of chemicals with existing registrations and labeled for the specified uses have been made for pepper, strawberry, perennials, tomato, and others. The effect on efficacy of chemicals with different rates of application, application methods, combinations of chemical alternatives, and the use of virtually impermeable films have all been tested. Methods have been developed that help control movement of pesticides from the treatment zone and predict pesticide movement in the environment, important to minimizing safety and environmental concerns. Unregistered chemicals, novel compounds and chemicals with potential label expansion have been screened and evaluated for herbicidal, nematicidal, and fungicidal activity. Pest complexes, as well as biochemical and environmental factors that contribute to production problems have been identified. Biologically and culturally based control strategies have been integrated with chemical controls into crop management systems and tested under commercial production conditions.

Selected Accomplishments:

Virtually Impermeable films (VIF)

Barrier films or virtually impermeable films (VIF) have demonstrated the capacity to reduce fumigant emissions through the plastic mulch to the atmosphere (1-8). Laboratory studies of the decreased permeability of VIF films have been confirmed by numerous field studies at several Florida and California locations. Typically, raised bed production systems for high value crops such as tomato and strawberry were the production system of study. In some cases, but not all, fumigation efficiency per unit of alternative chemical product per acre has been found to be greater when used in concert with VIF indicating that less product would be required than in polyethylene (PE) covered beds. Research is needed to understand why this result does not occur in all situations. Certain fumigants, especially high vapor pressure materials such as MB and methyl iodide, diffuse rapidly in all directions, including laterally to the row middles. A thin layer application of ammonium thiosulfate or thiourea functions as a reactive barrier and decreases the emissions of several fumigants including 1,3-dichloropropene (1,3-D) and MB itself (9). The concomitant advantage of using this material is that it could potentially supplement the nitrogen fertilizer in some production systems. A shortcoming that needs to be addressed before large scale acceptance of this technology will be possible is that VIF and comparable films are difficult to use.

In contrast, ARS scientists at Davis, California, found that ≥300 lbs/a rates of 1,3-D +chloropicrin or chloropicrin are required to approach efficacy of MB+chloropicrin and that use of VIF did not enhance pathogen control at depths of 12 inches or more in soil (10). Similarly, studies by ARS at Gainesville, Florida, showed that these low-vapor-pressure alternative fumigants lacked adequate dispersion to levels below 16 inches (4,5,6).

ARS scientists developed a new rapid, reliable and sensitive method to measure the permeability of agricultural films (11,12). The method yields a mass transfer coefficient (a measure of the resistance to diffusion through the film), which was found to better characterize inherent film permeability, since it does not depend on experimental conditions as do other methods.

Alternative chemistries in annual production systems

In strawberry, alternative fumigant research was conducted by ARS in conjunction with University of California-Davis scientists to assess the relative efficacy of MB (MB)+chloropicrin, iodomethane (IM)+chloropicrin, propargyl bromide, 1,3-dichloropropene (1,3-D) + chloropicrin, and chloropicrin for control of *Phytophthora cactorum* (10). Propargyl bromide was more effective than all other alternative fumigants and usually eradicated test inoculum of the pathogen. Furthermore, it was determined that ≥300 lbs/a rates of the 1,3-D-chloropicrin products or chloropicrin alone are required to get close to the efficacy of MB+chloropicrin. The California strawberry industry currently uses MB alternatives on more than 30% of its acreage, and assessments of IM+chloropicrin have contributed to registration efforts for the fumigant.

Propargyl bromide has been determined to be efficacious against most pests including nematodes, diseases, and weeds at rates above 100 pounds per acre, which is about 1/3 the current MB rate, and generally resulted in good plant growth and yield, although some phytotoxicity was noted in two trials. This information was generated by a multi-agency (ARS and university) and multi-state (California and Florida) effort that was carried out by studies on tomato, strawberry, carrot, fruit trees, grape vines, and ornamentals by 14 scientists from 6 locations with USDA funding. These coordinated studies indicate that propargyl bromide can be an efficacious replacement for MB. Although a private company expressed strong interest in registering propargyl bromide at the time these tests were being conducted, there is currently no private sector interest in pursuing registration of this material.

Phosphonates (a class of systemic fungicides that function by heightening host resistance and mediating toxicity to the pathogens) were found to be very effective for management of diseases caused by *Phytophthora cactorum* on strawberry in California (14). Widespread use of phosphonate application programs in strawberry, nursery, and fruit operations and in almond orchards has followed based on successful treatment and application technologies. Currently, these materials are used during the growing season as additional protection after initial fumigation. Phosphonate is considered to present little risk of environmental harm or development of pathogen resistance. Similar successful research was conducted on strawberries with mefenoxam (Ridomil Gold), an alternative systemic fungicide (15). These chemicals do not have efficacy across a range of target pests to make them general methyl bromide alternatives and would need to be used in combination with methyl bromide or alternatives to control the usual target pests.

Of sixty-five unregistered compounds evaluated for herbicidal and fungicidal activity in laboratory and greenhouse assays, six were identified with broad-spectrum, biocidal effects and two were field tested on multiple crops to confirm their activity. The combination of 2-bromoethanol and chloropicrin applied through drip irrigation lines was found to be as effective as MB for control of broad-leaf weeds, root-knot nematode and Pythium root rot in the cut flower *Celosia argentea*. Two patent applications have been filed on six of the novel compounds and a Cooperative Research and Development Agreement (13) was negotiated and entered into by ARS and Ajay North America, LLC. At this point these chemicals are not registered and are therefore, not available for use as alternatives.

A reduced-risk, iodine-based product, Plantpro 45 was field tested in multiple trials on tomato and strawberry and exhibited capacity to provide control of some soilborne pathogens but had no impact on root galling caused by root knot nematode (16). It was found to be effective as a seed and soil treatment for Fusarium wilt of basil (17) but lacks broad spectrum activity required of methyl bromide alternatives.

Perennial tree, vineyard, and nursery crops

Studies conducted to elucidate the etiology of replant disease of apple demonstrated the dominant role of fungi in development of the disease phenomenon, at times in concert with plant parasitic nematodes (18,19). These studies provided the biological foundation to substantiate previous findings obtained by scientists at Washington State University demonstrating equivalent or superior efficacy of chloropicrin over MB for the control of apple replant disease.

ARS scientists demonstrated that relative to MB, chloropicrin was more effective for the control of peach and almond replant diseases on sites lacking significant populations of parasitic nematodes (10). Focused, small doses of chloropicrin were as effective as higher doses, indicating that rate reduction and application optimization of pre-plant fumigation in orchards should be practical. The pronounced effectiveness of chloropicrin, as well as etiology, may dispel the notion that parasitic nematodes are the only important cause of replant disease of peach and almond. These findings may encourage more use of chloropicrin in tree fruit and nut industries, thereby lessening the need for critical use exemptions for MB and risk of exceeding Telone township caps. These tests were conducted in the special case where nematodes were not present or there in limited numbers, nematodes, however, are known to be important in many replant situations and in that case, chloropicrin would not be expected to be an adequate treatment.

Emulsified formulation of 1,3-D + chloropicrin applied through drip lines provided nearly equal benefits in growth and yield when replanting fruit tree orchards on sites expressing a demonstrable plant growth effect but where no acute pathogens or plant parasitic nematodes were detected (10,20,21). Control of plant parasitic nematodes in vineyard replant plots treated with 1,3-D + chloropicrin, IM+ chloropicrin, or propargyl bromide was comparable to control achieved by MB for up to 6 growing seasons regardless of application technology employed. Shank-injection and drip application of currently registered and non-registered materials in sandy loam soils provide control similar to that achieved with MB. Similarly, irrespective of application method, 1,3-D+chloropicrin and IM+chloropicrin (not currently registered in the United States) pre-plant fumigation provided nematode control in commercial tree and rose nurseries established on sandy loam soils. (1,3-D+chloropicrin does not provide adequate control when applied at maximum legal rates in heavy soils.) In these tests, when used in concert with tarping these alternative fumigants resulted in the harvest of nematode-free two-year crops similar in quality to crops grown in MB treated soil (22). However, control of fungi and nematodes with drip and shank-injected 1,3-D at maximum legal application rates was not as good as that achieved by MB at deeper soil depths in finer-textured soils. It should be noted township caps in California may limit availability of 1,3-D, and the label would need to be changed to allow higher application rates for 1,3-D to provide effective control for heavy soils.

Limited field trials in California evaluating alternative chemicals for pathogen and weed control in ornamental freesia, stock, snapdragon, iris, Gypsophila, and calla lily production systems showed that treatments containing chloropicrin applied with drip-fumigation technologies, resulted in per acre yields comparable to those obtained with the standard MB + chloropicrin fumigation (23,24). More trials need to be run to determine how well alternatives perform over time but some bulb growers have started using drip irrigation technology to apply MB alternatives to their fields resulting in a cost savings by elimination of in-season fungicide applications.

ARS scientists demonstrated that preplant applications of IM:chloropicrin and propargyl bromide delivered via shank injection reduced mycorrhizal colonization of replanted grapevines; however, these same fumigants applied via drip irrigation did not affect mycorrhizal colonization (25). Since root knot nematodes were controlled equally well by each application method, application of these chemicals through a drip system may reduce the negative effects on beneficial fungi while still controlling the target (pest) organisms in replant vineyards.

A series of drench and foliar-applied chemicals demonstrated that Subdue MAXX ® (mefonoxem) showed the greatest efficacy as a chemical control agent for soilborne fungal pathogens *Phytophthora ramorum* and other *Phytophthora* species (26). Thus, there are now several chemical alternatives that can be used in the nursery industry for the control of these pathogens.

Alternative application methods

Injection of preplant fumigants using a deep placement coulter system (Avenger®, Yetter Manufacturing Company, Colchester, Illinois, USA) developed by Mirruso Fumigation Company, Ft. Pierce, Florida, decreased the loss of fumigants to the atmosphere compared to chisel-shank injection (6,20). Decreased emissions to the atmosphere were presumable because of two factors; one, the coulter slice leaves less disturbed soil in the injection slit than does a chisel on a shank, and two, the system uses improved press wheels. Furthermore, coulter injection could be accomplished in undisked, settled soil which further decreased emissions to the atmosphere. Finally, coulter injection tended to provide a more uniform subsurface dispersion and distribution of 1,3-D and chloropicrin than chisel-shank injection or drip-tube application.

A novel apparatus was successfully developed to inject fumigants into the soil underneath established, raised, plastic-mulched beds (27). This ‘under bed fumigator’ was conceived, fabricated, and tested through a cooperative project with a custom fumigation applicator. Fumigation under raised beds covered with VIF dramatically reduced emissions of 1,3-D + chloropicrin and improved efficacy. The under bed fumigator mitigates regulatory hurdles associated with worker exposure and the use of personal protective equipment by separating the fumigant application from land preparation activities. It also allows growers to make more efficient use of their production fields by creating opportunities to disinfest soil in fields that do not have access to fumigant injection through drip irrigation systems. This program is recommended for small- to medium-scale producers of horticultural and ornamental crops with raised-bed, plastic-mulch production systems. A patent application has been submitted (28). United States Patent & Trademark Office on 3 October 2002 (Serial No.: 10/263, 107 and Docket No.: 0113.02)

A power-tiller was radically modified by ARS scientists for the application of metam-sodium (Vapam®), an alternative to MB, in conventional- and reduced-tillage systems (29). The integrated system of preplant application of metam-sodium and sequential optimally-timed application of halosulfuron was successful for control of perennial nutsedges in an array of cucurbits with minimal crop injury. Techniques for chemigating halosulfuron through drip-tape irrigation systems were validated in multi-crop production systems that include bell pepper, cucurbit crops, and eggplant sequentially grown on polyethylene covered beds (30,31,32). There are significant plant back restrictions for some crops on the halosulfuron label that might limit use in certain production systems.

In collaboration with manufacturers, applicators, and growers, ARS scientists demonstrated that drip fumigation is an effective management practice for the strawberry industry (33,34,35). Through 6 years of research and field demonstration trials, application equipment and procedures were developed and the technology transferred to growers. Furthermore, ARS research contributed to the registration of 3 drip formulations of fumigants: Telone EC (1,3-dichloropropene), TriChlor EC (chloropicrin), and InLine (1,3-D + chloropicrin). This drip-application technology has also been tested and demonstrated under commercial conditions in two orchards, three nut tree nursery fields and one rose nursery field (20,23).

ARS scientists identified deficiencies in uniformity of distribution of water through drip-irrigation systems, which would impact fumigant dispersion when such an application technology is employed. In California strawberry production systems, distribution uniformity varied from 45% to 93% and averaged 81%, resulting in the need for additional water (or drip applied fumigant) to achieve the target amount on the drier areas of the field (36). This work identified problems related to improper plot design, equipment, and management attributes contributing to the problem of limited fumigant distribution. Similarly,in Florida, chemical distributions of MITC released by drip-tube application of metam-sodium, and1,3-D chloropicrin (Telone-Inline®) in the soil in drip-tube applied beds were variable (4-8). Differential cross-bed soil compaction of the sandy Florida soil during the bed-forming process might have contributed to this problem, but the cause has not been determined.

Remote sensing has been developed as a means for monitoring plant growth and vigor in response to alternative fumigant treatments at Salinas, California, in conjunction with on-site plant growth and yield data of strawberry crops, with the long-term objective of using this technology also to monitor other grower inputs (such as fertility management) in the field, as well integrating it into their normal management decision practices.

Research and demonstration projects

An alternative fumigation program was developed through cooperative effort between ARS, the University of Florida – Gulf Coast Research & Education Center, a product development specialist from an agrichemical company and a commercial fumigant applicator. Twenty two large-scale demonstration/validation trials on commercial farms were conducted since 2000. Over 550 acres of commercial tomato and pepper farms were treated. Repeated applications were made at many sites for up to five consecutive years and no increase in pest populations was observed. Disease control was equivalent (within 5% of adjacent MB fumigated areas) in 20 trials, inferior in one and superior in one. Soilborne diseases present in the trial were Fusarium wilt and crown rot of tomato and Phytophthora blight of pepper. Nematode control was equivalent in all 22 trials. Weed control was inferior in 3 trials and equivalent to MB: chloropicrin in the remaining 19 trials. However, the results for these trials are misleading because these tests had only light nutsedge pressure. These trials need to be conducted with moderate to heavy nutsedge levels to adequately judge their efficacy under typical grower conditions.

Application costs for the broadcast-based alternative chemical program were $33 per acre lower than the MB standard based upon price estimates from November 2004. The addition of a third herbicide (Goal) raised costs an additional $11 per acre.

Over the past 5 years, a large-scale multidisciplinary field evaluation of alternative fumigants in strawberry production was conducted in California by University of California at Davis and ARS. Projects have included evaluation of alternative fumigants and methods of application (drip, VIF plastic) in strawberry nursery production (paper in press) as well as commercial fruit production fields. In addition to collecting yield data and conducting an economic cost/benefit analysis, basic information on fumigant distribution and degradation in the soil, efficacy of control of several pathogens, weeds, and nematodes at different depths in the soil profile, and estimation of LD_{90} for soilborne pests in natural field settings was collected (manuscripts in preparation). Laboratory dose-response studies are currently in progress to validate the results obtained from the field trials.

Large-scale evaluations and demonstrations of MB alternatives in commercial almond orchards and fruit and nut tree nurseries have been supported in part by USDA-CSREES. The ARS unit at Davis, California conceived and is co-coordinating this research. The trials will provide a basis for acceptance of alternative fumigation programs for production of certified nursery stock in California and for improvement in pre-plant fumigation strategies in commercial orchards.

Service

Continued use of MB after January 1, 2005, must fall into one of three categories: 1) use of stockpiled MB manufactured or imported prior to January 2005, 2) use which meets quarantine and preshipment criteria, or 3) has received an approved Critical Use Exemption (CUE). Growers and commodity commissions submitted CUE applications to the US EPA. Many of these applications used results of ARS research programs and ARS scientists were instrumental in providing reviews of these applications. CUE nominations submitted to the United Nations Environmental Programmes Ozone Secretariat are reviewed by the Methyl Bromide Technical Options Committee (MBTOC) and a recommendation is made to the Parties of the Montreal Protocol as to whether a critical use exists, and if so, how much MB is needed to meet that critical use. One ARS National Program Leader and one ARS scientist serve as members of MBTOC. Their participation on this committee helps to insure that the challenges faced by U.S. cropping systems and the technical and economic feasibility of MB alternatives for these cropping systems are better understood by the other members of the Committee.

Use of 1,3-dichloropropene (Telone) in California is limited by state “township cap” regulations. California pesticide use databases maintained by the state were analyzed to determine fumigant use trends and the likely impact of township caps on adoption of alternative fumigants that contain this chemical. The analysis showed severe impacts on certain commodities and geographic areas. These data are being used extensively by US EPA and Parties to the Montreal Protocol to evaluate Critical Use Exemption nominations for continued MB use for those circumstances where 1,3-D would be the only viable alternative, but is not expected to be available due to township caps.

Impact:

Producers now have access to definitive research confirming the efficacy of VIF film for decreasing fumigant emissions to the atmosphere, enhancing fumigant dispersion in the target treatment zone, and increasing the active concentration of fumigant in the soil However, VIF film treatment does not seem to promote dispersion of fumigants to greater depths in the soil profile. The plastic film-manufacturing industry now has the challenge of fabricating VIF film with improved handling properties for more effective installation than current VIF films, in raised-bed, film-laying operations in the field if this technology is to find widespread use among growers.

Information from several sources should give growers confidence to adopt coulter injection systems for decreasing emissions to the atmosphere. For cucurbit production, a modified power-tiller provides a more effective way to apply metham-sodium for consistent yellow nutsedge control at less cost than with MB fumigation. Also, halosulfuron is now registered for use on many cucurbit crops, and where double cropping plant-back restrictions are not an issue, will give commercial growers another tool for perennial nutsedge control.

As a result of ARS research, in collaboration with growers, manufacturers, university scientists, and applicators, growers of high value crops now have new emulsified formulations of 1,3-dichloropropene (1,3-D), chloropicrin (Pic), and 1,3-D + Pic registered for use. Drip application technologies for application of fumigants as alternatives to MB are now, under certain circumstances, in commercial use in strawberry and flower production systems in California. These new materials and new application technologies give growers options to consider when selecting the MB alternatives best suited to the particular circumstances of their cropping system. Furthermore, ARS research has also provided new knowledge for growers to use when deciding if technically and economically feasible alternatives exist for their cropping systems. However, in Florida, research has shown that uniform treatment and dispersion in raised-bed plasticulture is not usually achieved in Florida sandy soil with drip-tube chemigation. This system needs more research directed toward improving uniformity of dispersion of fumigants in sandy soils.

Growers have information from research and demonstration studies that document the efficacy (or lack of efficacy) of a range of labeled products from a wide range of agricultural and nursery productions systems. Furthermore, a wide range of other chemicals not yet labeled show a very strong potential for successfully functioning as alternatives to MB.

A large amount of information on the environmental fate and transport of fumigants in soil, water and air systems has been compiled regarding both MB and a number of alternative chemicals, and this information has led to an improved understanding of the processes that affect fumigants in soil. This new information makes it possible to develop better methods to apply and manage fumigants to minimize emissions and potential harmful effects from using these chemicals. The approaches to reduce fumigant emissions after application are being adopted by the producers and commercial applicators. Development of mathematical models offers the hope that quantitative fumigation management methods can be developed that will allow cost-effective decision making for site-specific conditions. This should help the farming community to safely continue using fumigation chemicals in a more restrictive regulatory environment.

Problem Area 1b – Biorationals

Outcomes, Goals, and Commitments: Critical goals for this problem area were to develop biological strategies to control pests, diseases, and weeds presently requiring methyl bromide soil fumigation either singly or in combination with chemical alternatives. Organisms and biorational products that have potential for control or suppression of diseases, weeds and nematodes and are nearing EPA registration or are in early stages of development have been screened. The role that soil microorganisms may play singly, or in combination with other control measures, in maintaining plant health has been investigated. Population dynamics and effects of biological control agents on native soil microorganisms, including those that are associated with replant disorder, have been determined. Biorational products have been evaluated for growth enhancement and induction of systemic acquired resistance to pathogens and nematodes.

Selected Accomplishments:

Biological control of plant pathogens and nematodes

ARS scientists have explored diverse biological approaches as alternatives to soil fumigation for the control of soilborne pathogens and nematodes. This research has been wide ranging and has included screening programs to identify new potential biological control agents, field evaluations of efficacy, identifying cultural practices that favor establishment of the antagonists and evaluating economic viability of their use.

Economically feasible alternatives to replace MB for management of nematodes and other soilborne plant pests are needed for vegetable growers. Biologically based alternatives are one approach, but they can be limited by inconsistent suppression of pests and by a narrow range of control. In a three year field study in a tomato cropping system in South Florida under conditions of low to moderate nematode populations it was demonstrated that biologically based treatments used in conjunction with nematode-resistant cover crops (velvetbean, sunn hemp) for suppression of nematode populations provided yields and net returns ($/ha) equivalent to, or greater than, treatments using MB + chloropicrin (1). Additional greenhouse and field trials with biologically-based products were conducted to determine their effects on plant growth, yield, and early season protection against nematodes and other soilborne pathogens in transplanted crops and several were identified that had a positive effects (2, 3, 4, 5, 6, 12, 13). Furthermore, commercial products marketed as inducers of systemic resistance and plant growth were tested in greenhouse and field trials and the effectiveness of several products was confirmed (14).

It has been postulated that root colonization by mycorrhizae yields plants that are more disease tolerant than plants without mycorrhizae (11). The mechanism contributing to such an outcome, however, is poorly understood. Research has demonstrated that formation of arbuscular mycorrhizae can result in modifications to the composition of microbial communities resident to the rhizosphere soil, including a significant increase in populations of rhizobacteria that can be antagonistic to soilborne pathogens. In an effort to enhance the ability of mycorrhizal fungi to colonize root systems in agricultural settings research has also been conducted to identify the influence of specific cultural practices on colonization (7, 8, 9, 10).

Biological control of weeds

Several plant pathogens and biologically-based compounds that are highly effective in controlling several agronomic, horticultural, and exotic invasive weed species were discovered and/or patented (19,20,21,22). In field tests, the fungus *Myrothecium verrucaria* repeatedly demonstrated a high capacity to control kudzu, a serious exotic invasive weed (15,16,18,19). Several companies have expressed interest in developing the fungus as a commercial bioherbicide.

Formulations, such as invert, oil emulsions, and granular, which greatly enhance the biocontrol efficacy of bioherbicides were also developed and patented (17,22). For example, the fungus *Colletotrichum truncatum* was found to be highly effective in controlling the weed, hemp sesbania in soybean, cotton, and rice fields when formulated with corn oil or invert emulsions, or with pre-emergence applications of fungus-infested wheat-gluten granules or rice formulations. Various surfactants, such as Silwet L-77, enhanced the virulence of *C. truncatum* for hemp sesbania control, and *C. gloeosporioides* for sicklepod control.

Research on field efficacy, optimal environmental conditions, host range and formulation effects indicated the potential of several biological control agents for weed pests including *Phomopsis amaranthicola* for control of pigweeds and amaranths, *Dactylaria higginsii* for control of purple and yellow nutsedge, *Dichotomophthora portulacae* for control of *Portulaca* spp., *Alternaria destruens* for control of dodder and several grass pathogens (23,24,25,26).

Ecological Evaluations of Biological Control

Research on biological control has been fraught with examples where disease control was attained in some locations or seasons but not others. In an effort to understand this variability in efficacy and develop approaches for optimization of the control response, ARS scientists investigated the ecology of biological control strains to identify the specific parameters necessary to attain disease management. For example, *F. oxysporum* strain CS-20 was found in some field trials to be efficacious in management of Fusarium wilt. Research was conducted to evaluate its efficacy over a range of temperatures, soil types and other environmental conditions, as well as compatibility with fungicides used to manage other pathogens (33,34). Research has also been undertaken to gain an understanding of how specific cultural practices or soil amendments can influence the ecology of soil microflora and result in a biologically based management of disease. For example, a comparison of populations of fungi and bacteria in soils from organic tomato production and conventional production revealed that the overall number of Fusaria and other microbes, as well as their diversity, was much greater under organic production (29,30). While a greater population of pathogenic Fusaria was isolated from the soil in organic production, diseased plants were observed at the conventional farm and not the organic farm. Genetic markers that differentiate between pathogenic and biocontrol strains of *Fusarium oxysporum* were identified and research is currently underway to determine if they are associated with biocontrol ability, as well as to screen for fungal strains with improved efficacy.

Numerous bio-based waste products have been used in plant production systems to enhance soil quality and control soil-borne plant pests. Previous studies have implicated the allelochemical activity of glucosinolate hydrolysis products as the operative mechanism in soil-borne disease control obtained in response to application of brassicaceous plant residues. However, findings from one ARS research program demonstrated that the control of Rhizoctonia root rot resulting from *B. napus* seed meal soil amendment functions irrespective of glucosinolate content (32,36). Specifically, populations of *Streptomyces* spp. native to orchard soils proliferated in response to seed meal amendment and individual isolates recovered from treated soils demonstrated the capacity to induce host defense responses. When evaluated within orchard soil ecosystems possessing a pathogen complex dominated by soil-borne fungi, pre-plant *B. napus* seed meal amendment employed in conjunction with a post-plant Ridomil Gold ® (mefenoxam) soil drench provided control of apple replant disease in a manner equivalent to pre-plant soil fumigation (35).

Research has also been undertaken to investigate the ecology of myxobacteria, a group of organisms relatively new to biocontrol research. Their survival in fumigated and organic soil and the role of strawberry plants as a source of inoculum was investigated using newly developed PCR primers. *In vitro* experiments in the laboratory and greenhouse evaluated the host range of specific fungal and bacterial species (31) and their ability to manage two fungal diseases of cucumber and lettuce.

The rhizosphere ecology of strawberry plants in fumigated vs. nonfumigated soil was studied and specific colonizers evaluated in growth chamber studies for their ability to enhance plant growth and in the field for their ability to enhance strawberry yield. Isolates were identified that significantly enhanced or reduced root length in growth chamber trials and enhanced yield in field trials (37). Results from this research confirmed that there are deleterious as well as beneficial rhizosphere colonizers of strawberry and identified strains that have potential as microbial inoculants.

Elucidation of Molecular Traits Associated with Biological Control

Understanding how plant-beneficial bacteria colonize plant roots and other plant surfaces will help predict how these beneficial organisms function in various soil environments and modify introduction strategies for more consistent disease suppression. A number of efforts aimed at elucidating important bacterial genes are underway in ARS research projects. For the plant-beneficial bacterium, *Enterobacter cloacae*, this was investigated by inactivating genes functioning in the three major pathways for carbon utilization (41). A mutant with an inactivated *rpiA* gene was totally deficient in colonization of roots while mutations in other pathways resulted in lesser impacts on colonization. In specific *Pseudomonas* spp., other genes associated with production of antibiotics attributed to biocontrol efficacy and regulation of their production also have been investigated (38,39,43). The genetic control of predation by a species of myxobacteria has been investigated as well (42).

On a much larger scale, the genome of the biological control agent, *Pseudomonas fluorescens* Pf-5, was completely sequenced (this is the first biological control agent for plant disease whose sequence is known). The genome sequence of Pf-5 highlights several important characteristics of the biological control agent, including its production of multiple antibiotics toxic to plant pathogens, its utilization of plant-produced nutrients, its capacity to utilize siderophores produced by a broad range of soil microorganisms, and the lack of genes required for pathogenicity. Sequence data will be used to develop basic knowledge of biological control, with the purpose of improving the consistent efficacy of biological control in agriculture.

In addition to investigating the molecular genetics of bacterial biocontrol agent, efforts also have been underway to identify specific genes associated with fungal pathogenesis and to evaluate their expression in hypovirulent isolates of *R. solani* capable of functioning as biocontrol agents. A down-stream metabolite of the shikimate pathway, phenylacetic acid (PAA), is a patho-toxin responsible for major symptoms caused by *R. solani*. Quinic acid, a carbon metabolite that competes with the shikimate pathway, was found to reduce the virulence of *R. solani* on potato. Recently the *arom* gene of the shikimate pathway was cloned and its regulation characterized in virulent and hypovirulent *R. solani* (40). Identification and characterization of the regulation of virulence associated genes are crucial to elucidating and exploiting the mechanism of hypovirulence.

Impact:

Before biological control agents will be used in commercial agriculture they will have to be effective in disease management, consistent in their control, and economically viable. ARS research programs have endeavored to address this need by conducting greenhouse and field trials with a number of different biorationals in various cropping systems to evaluate efficacy. Research also was conducted to evaluate the effect of combining applications with specific cover crops as a means for improving the consistency of control and providing an economically viable alternative means for pest control. This type of research is essential if biological control agents are to become an acceptable alternative means for pest management.

In certain production systems that currently rely on MB for pathogen control (for example, strawberry and tomato), soil fumigation also is the primary and most efficient means of weed control. Some fumigants that have been evaluated as alternatives are not as effective in controlling weeds, forcing growers to rely on more expensive and less effective means of weed management (hand weeding and when available, repeated herbicide applications). The identification of potential biological control agents for management of weeds will not only provide an additional tool for the growers to use, but in the long run reduce the dependency on chemical applications. ARS scientists have successfully identified new pathogens for weed control and have worked on improving formulation to ensure pathogen survival and increase the chances of host infection. Patents on some of these developments have been awarded and cooperative research and development agreements have been entered into with companies to facilitate commercialization of specific antagonists.

Development of alternative control measures becomes increasingly important as chemical pesticides, including MB, are removed from the market. Understanding the ecological relationships among the organisms involved, and the basic biology of biocontrol organisms can lead to more reliable biocontrol either through a better understanding of the conditions necessary for the survival and efficacy of introduced antagonists, or alteration in cropping or cultural practices to stimulate specific antagonists in soil to enable biocontrol. The work conducted with nonpathogenic strains of *F. oxysporum* clarifying ecological parameters associated with efficacy should facilitate the continued commercialization of these strains as biological control agents. Likewise, investigations on the rhizosphere ecology of strawberry plants to identify beneficial colonizers capable of enhancing yield in nonfumigated soil and evaluations of myxobacteria as biocontrol agents should provide new options for selection of potential antagonists. Of particular interest is the suppression of Rhizoctonia root rot of apple observed in response to *B. napus* seed meal amendment. This is a plant-mediated phenomenon (systemic acquired resistance) stimulated by elements of the soil microbial community. These studies provide a new paradigm that warrants further examination of the role of resident nitric oxide-producing *Streptomyces* spp. in brassicaceous residue-induced disease suppression.

The mechanisms by which biological agents control pathogens are often poorly understood. Clarification of the molecular traits associated with the ability of efficacious agents to colonize a plant surface or to produce antibiotics capable of controlling pathogens will allow scientists to employ a range of post-genomics technologies to enhance biological control capabilities. Studies in progress in several ARS laboratories have investigated this for several genera of biocontrol agents. The genomic sequence data that has been generated for strain Pf-5 of *Pseudomonas fluorescens* is posted on a publicly-accessible website and should become a significant resource in this research. The genome of Pf-5 can now be compared to the genome of related bacteria such as *Pseudomonas aeruginosa* and *Pseudomonas syringae*. Comparative genomics will advance knowledge of traits involved specifically in pathogenesis, as well as those involved in ecological fitness on plant surfaces or in soil.

Problem Area Ic - Cultural Controls

Outcomes, Goals, and Commitments: Critical goals for this problem area were to develop cultural control technologies that can be used alone, or in conjunction with other control technologies, for control of soilborne pests of vegetables and strawberries as an alternative to methyl bromide. In this problem area, definitive studies on efficacy of solarization, pest resistance, flooding, rotation, and cover crops have been conducted, efficacies determined, and possible roles in pest management systems have been investigated. New cultivars have been developed and evaluated for resistance to pests. Cultural technologies that can be used alone or in combination with other control methods have been developed.

Selected Accomplishments:

Host resistance for disease management

One of the most effective and economically viable means for the control of soilborne plant pathogens and parasites is the use of resistant cultivars in the agricultural production system. Significant progress has been made in the development and release of plant germplasm demonstrating resistance towards a variety of plant pathogens and parasites that have historically been controlled via the application of pre-plant soil fumigation. In certain instances, plant germplasm has been identified with resistance to multiple pests and/or has demonstrated efficacy to provide extended pest suppression through multiple cropping periods. Cultivars of sweet potato commonly grown in the United States are highly susceptible to many pests and soilborne pathogens. The cultivar 'Liberty', developed by ARS scientists, possesses major improvements currently not available in the old Boniato types like 'Piccadito' – such as high levels of resistance to root knot nematodes, 14 insect species, and disease incited by *Fusarium* spp (1). ARS scientists demonstrated that resistance in peppers, *Capsicum annuum* and *C. chinense,* to root knot nematodes is conferred by genes that are relatively heat stable (2,3,4); demonstrated via field studies that host resistance to root-knot nematodes is a feasible alternative to MB (5); and that the use of root-knot resistant pepper cultivars is a feasible method for managing root-knot nematode populations in soils used for growing other types of vegetable crops (6). Field screening of strawberry cultivars has determined that cultivars range from highly susceptible to moderately resistant to *Phytophthora cactorum*, and cultivars resistant to black root rot pathogens such as *Pythium* and *Rhizoctonia* were identified (7). Corky Root is a major bacterial diseases of lettuce to which all lettuce types are susceptible. Using greenhouse assays modified from published work a novel source of resistance was identified for this disease (8).

The application of plant resistance for disease control in perennial production systems is a more arduous task due to the biological complexity of the disease syndrome(s) that is typically targeted. However, peach rootstock resistance to ring and root knot nematodes has been identified (9) and such material will be of value for use in integrated strategies for the management of peach tree short life (10), and possibly replant disease.

Crop rotation, fallow periods and solarization for soilborne disease management

Crop rotation is commonly employed as a tool to manage soilborne diseases in annual cropping systems. However due to their complex etiology and the multiple pathogens and parasites that require control in such systems, the use of such a strategy in orchard environments for the control of replant diseases of tree fruits or other perennial crops, has met with limited success. Pre-plant cropping of orchard soils with wheat was shown to provide control of plant parasitic nematodes in peach and apple (11,12). In addition, such a management strategy resulted in the development of suppressive soil to Rhizoctonia root rot of apple by inducing the proliferation of fluorescent pseudomonad genotypes that demonstrate antagonistic activity toward the causal fungus *Rhizoctonia solani* (13,14). Of significant scientific import, this phenomenon was shown to be induced in a wheat genotype specific fashion. In micro-plot studies, a single summer rotation of Sudan grass dramatically lessened the severity of peach replant disease, with the benefit approaching that achieved through preplant MB-chloropicrin soil fumigation (15). ARS scientists and collaborators demonstrate that crop rotation with broccoli or brussels sprouts was an effective practice for the control of Verticillium wilt of strawberry. However, due to economic concerns these rotation practices are not currently being implemented in conventional strawberry production systems. The use of bare fallow as a soilborne disease management strategy exhibited differential impacts on plant growth in these production systems. In apple, a three-year fallow had no impact on development of replant disease or root infection by the causal pathogen complex (16). Similarly, short-term fallowing did not significantly alter the severity of replant disease of peach and plum and resulting yields (15,17), however in the absence of a significant nematode component, a three year fallow period prior to planting resulted in yields that were equivalent to pre-plant MB fumigation (17).

Rye has been employed extensively as a cover crop for the control of plant parasitic nematodes. The nematicidal nature of rye was examined by ARS scientists. Specific cyclic hydroxamic acids, secondary metabolites produced by this plant, were found to possess activity against the plant parasitic nematodes *Xiphinema americanum* and *Meloidogyne incognita*. However, these nematodes, and their life-stages, demonstrated diverse sensitivities to the multiple hydoxamic acids produced by rye (18). Rotations with canola or tall fescue, or weed-free fallow were as effective as fumigation with MB in preventing re-infection of raspberry plants with nematode transmitted tomato ringspot virus.

ARS scientists demonstrated the value of pre-plant solarization treatments, as a solitary practice or as part of an integrated strategy, for the management of certain plant pests and pathogens, in climates not previously considered suitable for the application of such a management approach. Soil solarization used as a component of an integrated management strategy in the Pacific Northwest was shown to be highly effective for the management of soilborne pathogens in raspberry (19). In the southeast United States, solarization was shown to significantly reduce yellow nutsedge populations resulting in benefits to the subsequent curcubit crop (20, 21). Soil solarization resulted in marketable yield of pepper under a certified organic production and in conventional production systems that approached the Florida state-wide average for conventional systems that employ MB soil fumigation (22).

Impact:

For the first time, a multiple pest resistant, dry-fleshed sweet potato cultivar has been released to replace the pest susceptible variety brought from Cuba in 1960, and currently grown in South Florida. It will also provide an adapted pest resistant cultivar for California growers that grow similar types for the export market. Since sweetpotato is the 7th largest crop in world production, and the majority of the world eats a dry-fleshed type, 'Liberty'can be adopted as a new multiple-pest resistant cultivar and/or a parent source of multiple pest resistance to improve the crop world-wide. Host plant resistance is now viewed by the pepper industry as a feasible alternative to MB for controlling root-knot nematodes. Seeds of resistant *Capsicum* cultivars and germplasm developed by ARS continue to be distributed worldwide, and leading commercial seed companies are using these materials to develop resistant cultivars. The accomplishment provides an alternative management method to pre-plant MB fumigation for managing root-knot nematodes in cucurbits in double cropping systems where pepper is employed as the initial planting.

Studies have demonstrated the importance of specific pathogens in strawberry production systems, which were not previously believed to be important limits to yield, and methods have been developed and employed to evaluate the susceptibility of commercial cultivars to these pathogens. Development of effective screening programs will assist in the identification of disease and pest resistance and will facilitate breeding efforts to introgress this resistance into commercial cultivars, thereby obviating the need for soil fumigation.

Though crop rotation is a commonly employed practice for management of soilborne diseases, the general consensus is that such a strategy functions through limiting pathogens and parasites of a susceptible plant host. Findings from these studies have demonstrated alternative mechanisms, including the selection of specific resident soil microbial anatagonists which directly inhibit plant pathogenic fungi and identification of the functional nematicidal compounds, that contribute to the disease control observed in response to the use of crop rotation. Identification of these mechanisms will allow for the selection and application of plant genetic material with an enhanced capacity to function as rotation crops for the control of the targeted pathogens and parasites. The wheat rotation technology has been transferred to tree fruit producers, and has been employed in situations where orchard re-establishment can be delayed for the duration of the wheat cropping period.

Cultural controls are generally the most cost-effective and sustainable methods of managing weeds in vegetable cropping systems where MB was the dominant practice employed for weed control. In the absence of MB, application of polyethylene mulch to suppress emergence of perennial nutsedges in vegetable production systems will provide a weed control option that is more cost effective than MB. Fallow tillage or summer solarization will be an applicable long-term weed control option. Although the disease and pest control benefits of soil solarization have been acknowledged in hot, dry climatic zones, for certain pest problems producers now possess information documenting the utility of this treatment in areas that were previously deemed sub-optimal or intractable to its application.

Although cultural controls have demonstrated efficacy under field conditions, the application of these technologies continue to be limited by the narrow spectrum of pests and pathogens for which any one treatment can provide adequate disease, nematode or weed control. As such, continued effort is necessary to the design of effective integrated strategies which incorporate elements that have been identified in these studies.

APPENDIX 1 - SELECTED SUPPORTING INFORMATION AND DOCUMENTATION FOR ACCOMPLISHMENTS AND IMPACT OF NP 308 RESEARCH

Component I – Preplant Soil Fumigation Alternatives

Problem Area 1 a – Chemical Controls

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APPENDIX II - MAJOR COOPERATORS AND CONTRIBUTORS TO PREPLANT RESEARCH PROGRAMS

Component I: Preplant Soil Fumigation Alternatives

Problem Area Ia - Chemical Controls

Virtually Impermeable films (VIF)

1. Scientists at the University of Florida contributed a field site, fumigant injection or application and plastic bed covering systems (Dr. Donald W. Dickson) as well as laboratory facilities for fumigant analysis of air-pore concentrations and surface emissions over a number of days after application (Li-Tse Ou, and John E. Thomas). [Location: Gainesville, FL. Lead Scientist—Allen]

2. Scientists at the University of Florida contributed to VIF research collaborations both through Fort Pierce and the Research and demonstration Project (Jim Gilreath). [Location: Fort Pierce, FL. Lead Scientist—Chellemi]

3. Scientists at the University of California-Riverside (J. Gan, M. Guo, D. Wang, Q. Wang, W. Zheng) contributed to reduction of fumigant emissions studies. Dow AgriSciences LLC, Indianapolis, IN, AMVAC Chemical Co., Calgon Carbon Co. provided financial support, product, and product information. [Location: Riverside, CA. Lead Scientist—Yates]

Alternative application methods--injection

1. Dow AgroSciences provided the Yetter Avenger® coulter systems (Yetter Manufacturing Co., Colchester, Illinois, USA) for injection of Telone products [Locations: Gainesville and Fort Piece]; Mirruso Fumigation Co, Ft. Pierce, FL, participated as a cooperator in the development of an under-bed fumigation system; Tony Wiess and Jerry Nance, Dow AgriSciences, served as cooperators on alternative fumigant trials. [Location: Fort Pierce. Lead Scientist—Chellemi]

2. University of Georgia scientists Dr. A. S. Culpepper contributed expertise in herbicide/fumigant application technology and assisted in technology transfer of findings from studies on the use of alternative fumigants for control of nutsedge in cucurbit production systems, and Dr. A. S. Csinos contributed expertise in plant diseases and application technology. [Location: Tifton, GA. Lead Scientist—Johnson]

Alternative chemistries in annual production systems

1. Strawberry fumigation trials in California were conducted as part of a large multidisciplinary project funded through the USDA-CSREES that included a soil scientist (Husein Ajwa, UC Davis), a weed scientist (Steve Fennimore, UC Davis), three plant pathologists (Greg Browne, USDA-ARS at UC Davis, John Duniway, UC Davis,

and Frank Martin, USDA-ARS in Salinas), a nematologist (Becky Westerdahl, UC Davis), and an agricultural economist (Rachel Goodhue, UC Davis). Trials were conducted with personnel support from the California Strawberry Commission (Christopher Winterbottom and Louis Guerrero), the strawberry nursery plant industry (Lassen Canyon and Sierra Cascade nurseries), and commercial fruit production growers (Martinez Berry Farms, Dole, and several others). [Location: Salinas, CA. Lead Scientist—Martin]

2. Land, planting material, labor, and commercial expertise were provided for field trials conducted under commercial conditions by the following: Jackson and Perkins Roses, Wasco, CA; L.E. Cooke, Inc., Visalia, CA; Burchell Nursery, Oakdale, CA; Sierra Gold Nursery, Yuba City, CA; Brights Nursery, LeGrande, CA; Dave Wilson Nursery, Hickman, CA; Dramm & Echter; Golden State Bulb Co.; Mellano & Co.; Pyramid Flowers; Hilltop Flowers; Brand Flowers; John Dullum; Darren Gee; Glenn Imoto; Stuart Yamamoto; Rod Koda; Miguel Ramos; California Strawberry Commission; Juan Perez. Commercial methyl bromide applications were contributed by Tri-Cal, Hollister, CA. Chemicals for the field trials were donated by Dow AgriSciences, Arvesta, Niklor, Amvac, Albemarle, Cal-Agri Products. 30 Strawberry Growers allowed access to their commercial production fields for the measure of irrigation uniformity through their strawberry fields. Several Scientists contributed significant knowledge and experience to identification and development of alternatives to methyl bromide for orchard replant and perennial nursery situations (Drs. Greg Browne, ARS, Bruce Lampinen, UC Davis, and Anil Shrestha, UC Statewide IPM program); to knowledge and experience in drip-fumigation (Dr. Husein Ajwa, formerly of ARS, now UC Davis). [Location: Parlier, CA. Lead Scientist—Schneider]

Perennial tree, vineyard and nursery crops

1. Major research partners, all of which provided financial and/or in-kind support, include the Almond Board of California, The California Strawberry Commission, USDA-CSREES, TriCal, Inc., Burchell Nursery, Inc.; Sierra Gold Nursery; Bright's Nursery; and Dave Wilson Nursery. Major collaborators and cooperators, all of which contributed specialized expertise in their respective areas of science, include Husein Ajwa, UC, Davis; Joe Connell, UCCE, Chico; John Duniway, UC, Davis; Steve Fennimore, UC, Davis; Chris Heintz, Almond Board of California; Brent Holtz, UCCE, Madera; Dan Legard, California Strawberry Commission; Frank Martin, USDA-ARS, Salinas; Sally Schneider, USDA-ARS, Parlier; Anil Shrestha, UC, Parlier; Leo Simon, UC, Berkeley; Tom Trout, USDA-ARS, Parlier; Becky Westerdahl, UC, Davis; and Christopher Winterbottom, Sierra Cascade Nursery. [Location: Davis, CA. Lead Scientist—Kluepfel]

2. Research on the impact of fumigation in vineyard replant trials on subsequent mycorrhizal colonization of grape was conducted in cooperation with ARS scientists (Sally Schneider and Dave Bryla) at Fresno, CA. Research on chemical control of conifer seedling damping-off was conducted in cooperation with Charles Masters of the Weyerhaeuser Company. [Location: Corvallis, OR. Lead Scientist—Linderman]

Problem Area 1b – Biorationals

Biological control of plant pathogens and nematodes

1. Work on biocontrol of plant pathogens is done in collaboration with Dr. J. W. Kloepper, Auburn University and Don Kenny, Gustafson LLC, a partner in a CRADA. Collaborative research also has been established with Dr. Debora Fravel, USDA-ARS, Beltsville. [Location: Ft. Pierce, FL. Lead Scientist—Chellemi]

2. Collaborative projects have been established with Dr. W. Klassen, TREC, University of Florida, Homestead, FL(Field trials with cover crops), Dr. Y. Li, TREC, University of Florida, Homestead, FL (Field trials with cover crops), Dr. S.L.F. Meyer, USDA ARS, Beltsville, MD (Development of microbial biological controls) and Dr. I. Zasada, USDA ARS, Beltsville, MD (Development of microbial biological controls). [Location: Beltsville, MD. Lead Scientist—Fravel]

Biological control of weeds

1. Dr. R. Charudattan, University of Florida, Gainesville, FL-patent co-holder, contributes knowledge on pathogen culture and application. [Location: Ft. Pierce, FL. Lead Scientist—Chellemi]

2. Collaborative research projects has been established with Dr. W.J. Connick, Jr., USDA ARS (ret.), New Orleans, LA (Bioherbicide formulation), Dr. D. J. Daigle, USDA ARS (ret.), New Orleans, LA (Bioherbicide formulation), Dr. M. A. Jackson, USDA ARS, Peoria, IL (Mass production of inoculum), and Dr. P. C. Quimby, Jr., USDA ARS (ret.), Beltsville, MD (Bioherbicide formulation). [Location: Stoneville, MS. Lead Scientist—Boyette]

Ecological Evaluations of Biological Control

1. Dr. Kent Mullinix and the Pomology program at Wenatchee Valley College contributed orchard sites and management services to the conduct of this research program. Mr. David Granatstein, Center for Sustaining Agriculture, Washington State University contributed knowledge of the production system and potential limits within this system to the adoption of novel disease management strategies. [Location: Wenatchee, WA. Lead Scientist—Mazzola]

2. Collaborative research has been established with Dr. Dan Chellemi, USDA, ARS, Ft. Pierce, FL who developed working relationships with Florida tomato growers whose fields were sampled. [Location: Beltsville, MD. Lead Scientist—Fravel]

3. Role of Myxobacteria in Agricultural Soils: research is done in collaboration with scientists at the University of California, Davis, Department of Microbiology and the University of West Florida. Research on strawberry rhizosphere colonizers and

identification of specific rot pathogens for control was supported in part by the California Strawberry Commission. [Location: Salinas, CA. Lead Scientist—Martin]

Elucidation of Molecular Traits Associated with Biological Control

1. The *Pseudomonas* genome was sequenced at the Institute for Genomics Research, under the direction of Ian Paulsen, in collaboration with J. Loper and C. Press at the Horticultural Crops Research Unit in Corvallis, OR; L. Thomashow, Root Disease and Biological Control Unit, Pullman, WA; L. S. Pierson III, U. Arizona; and D. Kobayashi, Rutgers University. Outside funding from the USDA-CSREES Microbial Genome Sequencing Program was essential for this accomplishment. Also, collaboration with The Institute for Genomic Research, Rutgers University, and the University of Arizona was key. [Location: Corvallis, OR. Lead Scientist—Linderman]

2. Molecular characterization of root colonization genes has been done in collaboration with D.Y. Kobayashi, Rutgers University, New Brunswick, NJ. [Location: Beltsville, MD. Lead Scientist—Roberts]

Problem Area Ic - Cultural Controls

Host resistance for disease management

1. Disease Resistance for Disease Management: Funding for this work was provided by the California Lettuce Research Board. [Location: Salinas, CA. Lead Scientist—Martin]

2. Growers located in South Carolina (Gallop Farms, Earhardt, SC) Florida (Brooks Tropical, Homestead, FL) and California (Doreva Produce, Livingston, CA) contributed field sites for the evaluation of the sweet potato cultivar Liberty. [Location: Charleston, SC. Lead Scientist—Bohac].

3. Scientists at Clemson University and the University of Florida contributed knowledge of the production systems as well as field sites for studies assessing the resistance of pepper cultivars to root-knot nematodes. [Location: Charleston, SC. Lead Scientist—Theis]

Crop Rotation, fallow and solarization

1. Dr. Paul Bertrand, University of Georgia Cooperative Extension Service, Tifton, GA, contributed to the technology transfer of wheat rotation strategy for the control of ring nematode in peach production systems. [Location: Byron, GA. Lead Scientist—Nyczepir]

2. Studies on the use of wheat cropping systems for the management of Rhizoctonia root rot of apple and the mechanism of action were conducted with financial support from the Washington Tree Fruit Research Commission and the National Research Initiative Competitive Grants program. [Location: Wenatchee, WA. Lead Scientist—Mazzola]

3. The Almond Board of California, The California Strawberry Commission, Burchell Nursery, Inc., Sierra Gold Nursery; Bright's Nursery; and Dave Wilson Nursery provided financial and/or in-kind support, and numerous University of California-Davis scientists contributed knowledge in the study of rotation systems for the control of peach replant disease. [Location: Davis, CA. Lead Scientist—Kluepfel]

4. Investigations concerning the use of crop rotation for the control of Verticillium wilt in strawberry was conducted in collaboration with Dr. Krishna Subbarao (UC Davis), and Steve Koike (UC Cooperative extension) assisted in plot management with trials hosted by Dole Berry. Financial support was provided by the California Strawberry Commission and the California Department of Pesticide Regulation. [Location: Salinas, CA. Lead Scientist—Martin]

5. Studies on the application of solarization for the control of soilborne diseases in raspberry were conducted in cooperation with Dr. Pete Bristow, Washington State University. Location: Corvallis, OR. Lead Scientist—Linderman]

6. Drs. A. S. Culpepper and Terry Kelley from the University of Georgia contributed expertise and assistance in technology transfer for studies concerning the application of solarization for nutsedge control in curcubit production systems. [Location: Tifton, GA. Lead Scientist—Johnson]

7. Drs. Jim Graham (University of Florida) and Kendall Martin (Univ. North Florida) contributed expertise, and Osceola Organics and Triangle Farms, provided field sites and technical advice in studies investigating the use of soil solarization for disease and pest control in Florida pepper production systems. [Location: Ft. Pierce, FL. Lead Scientist—Chellemi]

Research Component II – Postharvest Commodity Treatment (Including Structural)

Methyl bromide is used to maintain postharvest commodities free of insects and mites. Condition and grade of commodities can deteriorate quickly in the absence of effective postharvest insect control. Maintenance of quality is essential if American products are to remain competitive in the world market place. Food processing plants such as flour mills, rely on methyl bromide for structural disinfestation of insects required by health authorities as well as to keep insects from infesting manufactured products. Approaches will include heat, cold, controlled atmospheres, irradiation, chemicals including other fumigants, exclusion, and new exotic pest eradication technology.

Problem Area IIa - Methodologies to maintain quality of stored durable commodities

Outcomes, Goals, and Commitments: Critical goals for this problem area were the development of methodologies that replace methyl bromide fumigation for stored durable commodities (tree nuts, dried fruit, grain, milled products, museum artifacts, etc.) for quality maintenance. Methods to detect pests in these commodities have reduced the need for fumigation. Alternative fumigants have been investigated and phytotoxicity determined. Protectant insecticides have been shown to reduce the need for fumigation of cut flowers. The logistics of using radiation on a commercial scale have been investigated. The use of heat and controlled atmospheres has been examined in commercial scale studies.

Selected Accomplishments:

Heat/Cold Treatments

Because the quality and marketability of dried fruits and nuts are seriously compromised by the presence of insects, processors have long relied on fumigants, particularly methyl bromide, to disinfest product. Various physical treatment methods are being considered as non-chemical alternatives to fumigants (11,12,13,14,15,18). The relative heat tolerance of postharvest insect pests of walnuts was determined and used to devise radio frequency treatments which provide rapid disinfestation of the product without adversely affecting product quality. Using this information, one walnut processor is in the process of testing the applicability of a radio frequency heating unit to treat their product under commercial conditions. At the other end of the temperature spectrum, the effect of commercial cold storage on survival and reproduction of several postharvest insect pests was determined and now bean processors have a better understanding of the treatment times necessary to disinfest dry beans of cowpea weevil; and one processor has effectively shortened treatment times by 10 days (12). Cold storage was also shown to protect dried fruit and nut commodities from infestation by Indianmeal moth. This information has been used by dried fruit and nut processors in designing storage facilities and product handling procedures, and can be of use to other stored food industries in maintaining insect-free product that will retain its high quality.

Biological Control

Agents such as pathogens and parasites may be useful in limiting populations of postharvest insect pests of dried fruit and nut commodities and reduce the need for fumigation treatments. A product containing a granulosis virus for control of the Indianmeal moth, based on a process previously patented by the ARS, was developed, licensed and registered for use as a protectant for postharvest dried fruits and nuts (17). The virus was shown to be very effective in protecting almonds and raisins from damage by Indianmeal moth, and various methods of application to bulk stored product were studied. It was also demonstrated that the virus could be used in conjunction with the alternative fumigants phosphine, sulfuryl fluoride, and carbonyl sulfide with no loss of potency. Additionally, a entomophagous nematode preparation was found to control overwintering navel orangeworm larvae in fallen pistachios more effectively than normal disking practices used now (16). Reduction of overwintering navel orangeworm populations improves overall control of this prevalent postharvest nut pest by reducing the numbers of insects that survive the winter months.

Pheromone Attractiveness and Trapping

Better prediction of insect infestations leads to a more timely response and results in longer shelf life and better quality while eliminating unnecessary fumigations. A better pheromone mixture for navel orangeworm has been developed that includes chemicals heretofore undetected in the natural pheromone. This newly constituted pheromone has greatly increased the reliability of experiments to show the effects of pheromones on insect behavior and thus increased the speed with which research can obtain results in field studies with alternatives to methyl bromide.

ARS researchers have accumulated a large pheromone monitoring dataset on stored-product pests in commercial food facilities and the impact of fumigation on these pest populations under field conditions (1,2,3,4,9). Long-term pest monitoring data were collected from multiple flour mills, over several years, and with multiple fumigations performed at each location. These data were used to evaluate seasonal patterns in insect activity, spatial distribution of pest populations, fumigation efficacy, and the factors that influence fumigation efficacy and post-fumigation rebound (7,8). Initial data on the impact of sulfuryl fluoride and aerosol insecticide treatments on pest populations were also collected. Results suggest that action thresholds can be developed for red flour beetle and that population rebound rate can be manipulated to increase the time period between fumigations.

ARS scientists have been involved in the development of contour analysis of pheromone trap catches as a means of monitoring stored product insects in buildings so that points of entry and foci of infestation can be located and pest management more effectively targeted by using “precision control” (4). The premise that there is a direct relationship between trap catch and proximity to a source of infestation was tested in pilot scale shed studies and studies in commercial facilities and the premise was supported for both stored product beetles and moths. The relationship between trap catch and distance from a source of insects was determined (2,3). ARS research has also determined various sources of error in predicting insect distribution by trapping and contour analysis and pointed out measures that can be taken to minimize them.

Alternative Fumigants/Aeration

Carbonyl sulfide and methyl iodide were shown to be a potential replacements for methyl bromide in the fumigation of lemons for California red scale, *Aonidiella aurantii* (5). Using methyl iodide caused some phytotoxicity until it was discovered that prolonged forced aeration following fumigation alleviated the phytotoxicity (5,6). In addition, methyl iodide and sulfuryl fluoride showed promise in controlling eggs of the codling moth, *Cydia pomenella* on nectarines (6).

Impact:

Industry now has a rapid alternative disinfestation treatment for postharvest walnuts. Thermal death data have identified the most heat tolerant insect species and stage which may also be used by scientists to develop other types of heat treatments. In addition to knowledge of the response of cowpea weevil to freezing temperatures, cooling rate data for bean bins in commercial freezers may be applied to other commodities. Such information is of use to both bean processors and researchers developing other cold storage treatments. Industry now also has information on the effect of cold storage on Indianmeal moth development and reproduction, and evidence that cold storage can effectively protect product from infestation. Dried fruit and nut processors now have a registered non-chemical virus-based protectant that is effective against the Indianmeal moth, one of the most prevalent pests of stored foods. Information on the best use of the product is now available to industry and researchers. Information on the compatibility of this product with chemical fumigants will be used to develop integrated management programs. This product may also be of use in other commodities.

Information on the temperature and moisture requirements for effective use of commercial nematode preparations is now available to growers, and will enable them to improve control of overwintering navel orangeworm and thus reduce the infestation and need for methyl bromide fumigation.

Through the work on the population dynamics in the field and pheromone development, much more is now known about the damage and control of navel orangeworm in pistachios and almonds and of dried fruit beetles in figs in the field. These studies have led to better use of treatments to reduce damage and in the emphasis for controlling the navel orangeworm. The monitoring data generated from storage and processing facilities has been used to evaluate the effectiveness of methyl bromide fumigations and helps provide a baseline for comparison with alternative tactics. This research has highlighted the challenges of evaluating efficacy in spatially complex environments such as food facilities, but provides information from which scientists can develop mathematical models to predict pest populations and produce flexible action thresholds for the food industry. By using a good monitoring program and manipulating the rate of pest rebound, the need for fumigations could be reduced in food facilities such as mills, processing plants, and warehouses.

The scientific community now has a new way to look at potential fumigants and how they cause phytotoxicity in citrus. These studies suggest that forced aeration may allow a wider use of potential fumigants than was previously thought. It may be possible for the U.S. citrus industry now to export citrus using methyl iodide and forced aeration instead of methyl bromide. Because quarantine schedules often require methyl bromide as the treatment specified by the importing country, the research on alternative compounds like methyl iodide (if it is registered for this use), sulfuryl fluoride and carbonyl sulfide provides a basis for modifying these schedules to eliminate methyl bromide usage.

Improved pest monitoring methods resulting from ARS research accomplishments have provided tools that can be used by scientists, managers, sanitation personnel, and pest control operators to detect and locate foci of infestation or points of entry. This pinpointing of trouble spots facilitates denial of access to pests and precision targeting of management interventions, thus reducing the need for fumigation and minimizing the use of other chemical treatments. Trapping and contour analysis are already being used in the pest control industry. Contour maps of trap catch graphically portray the magnitude and spatial extent of an infestation, which aids in identifying contributing factors, assessing the effectiveness of control measures, and communicating insect problems to management and other personnel.

Thus, these several new or potential treatments and monitoring methods will now allow the continued movement of horticultural crops in world commerce without resorting to methyl bromide. These new treatments will maintain quality in exported commodities without the use of methyl bromide and in many cases provide better quality than was previously possible.

Problem Area IIb - Quarantine treatments for export of commodities and provision of technical assistance to APHIS to gain acceptance of these procedures by trading partners.

Outcomes, Goals, and Commitments: Critical goals for this problem area were the development of methodologies that replace methyl bromide quarantine treatments for export of commodities including cherries, peaches, nectarines, and other stone fruit, apples, grapes, strawberries, and other berries, cotton, etc. and provide technical assistance to APHIS to gain acceptance of these procedures by our trading partners. A systems approach has been developed that limits pest populations so that fumigation is not necessary. New fumigants and protectant chemicals have been tested and efficacies determined. The logistics of using radiation on a commercial scale have been investigated, and a method has been developed to show the irradiated insects cannot reproduce. The use of heat and controlled atmospheres has been examined in commercial scale studies. Commercial-scale studies have determined the feasibility of heat and controlled atmospheres to control pests. Alternative treatments for wood pallets have been developed. ARS scientists have collaborated with APHIS on the results of studies so that APHIS, as well as importing countries, can be confident that the treatments will really work and that pests will not be introduced into trading partner's countries.

Selected Accomplishments:

Systems Approach

In order to reduce the use of methyl bromide fumigation and other quarantine treatments, research on the systems approach has produced treatments for cherries that depend upon integrated technologies that are used throughout the growing season and eliminate the need for fumigation upon export. These systems eliminate pests of quarantine interest from the cherries while they are growing (19,21,22,23,24,40). Such cherry production areas are now under consideration for acceptance by Japan as an alternative to methyl bromide fumigation of export cherries (20,21,22,23,24).

Methyl Bromide

A quarantine schedule using methyl bromide was developed for the shipment of fresh prune plums to Japan (28). This treatment allows Japan to accept fresh prune plums from the U.S. while maintaining its quarantine against codling moth. One variety was tested initially and another was accepted later. In addition, methyl bromide schedules were tested against two new varieties of cherries for acceptance by the Japanese under the new agreement on the testing procedures for new varieties.

Alternative Fumigants

Compounds that have potential to replace methyl bromide for quarantine uses have been investigated for use on different commodities. Several potential fumigants were shown to have potential to replace methyl bromide if necessary in quarantine treatments of walnuts. These potential treatments consisted of carbonyl sulfide, methyl iodide, sulfuryl fluoride, and propylene oxide. Phosphine in combination with compression has been shown to be effective in eliminating live Hessian flies and cereal leaf beetle from Timothy hay bound for Japan (41,43,4). This treatment can now be used on small or large compressed bales of the hay (44). Ozone was shown to be a useable replacement for methyl bromide in eliminating adult thrips from the navels of oranges being exported to Australia. Tests established the schedule needed to kill all thrips in a chamber designed to treat with ozone gas mixed with a low concentration of carbon dioxide (29). Tests are now underway to identify the types of waxes used on oranges that will help protect the orange from any phytotoxic effects caused by the ozone.

Controlled Atmospheres

Effective controlled atmospheres, containing ultra-low oxygen (ULO), were developed for control of lettuce aphid without injury to lettuce (30). This has resulted in greater efforts to find effective ULO treatments for control of other quarantined pests including western flower thrips and leafminer flies on lettuce. The lettuce industry has also shown great interest in ULO treatments for postharvest insect control. Controlled atmosphere treatments have been developed for the Mexican Fruit fly infesting grapefruit and have proved successful on a semi-commercial scale (1). Host status studies have shown that walnut husk fly, which is a native fruit fly, does not prefer peaches and nectarines, thus opening export markets, based on poor host status, for peaches and nectarines where none existed because of quarantine concerns for the fly (40).

Combination Systems

Sometimes by combining different techniques, a treatment can be developed that takes advantage of the attributes of each contributor to the combination. Development of a controlled atmosphere/temperature treatment system (CATTS) has been shown to be efficacious and non-injuring to fruit for disinfestation. CATTS technology has been tested both in the laboratory and in commercial settings and provides an viable potential alternative to methyl bromide for quarantine uses (32,33,35,36).

Physical Control (Heat, Cold and Irradiation)

In the production of exotic fruit and vegetables in Hawaii, studies in heat and cold treatment resulted in the export of litchi, longan and papya to the mainland and foreign countries (7,8,37,38). Irradiation research has also resulted in treatments for these commodities plus mangos, rumbutan and sweetpotatoes (14,39). Tests of irradiation as a quarantine treatment against the most tolerant stages of several insect species have shown that 400 Gy is a secure dose (8,13). Cold treatments have been developed for the above named commodities plus avocado and carambola. Forced hot air treatments for citrus have proven successful for eliminating live Mexican fruit flies from grapefruit and ohmic heat has proven promising to disinfest apples of the apple maggot (18).

Impact:

Methyl bromide fumigation of fresh prune plums to eliminate codling moth has allowed the plum industry to ship plums to Japan. This quarantine schedule allows millions of dollars worth of plums to be exported from California where a large planting of the plums has resulted in an excess of the fruit. Up until now, the processors of postharvest commodities had only phosphine and methyl bromide to rely upon. With the information developed, they now know that several new potential fumigants exist and that they may be useful alternatives to methyl bromide in both control and quarantine fumigations. CATTS technology has provided the export fruit industry with a viable treatment system that avoids a chemical fumigation treatment while providing pest-free, quality fruit for export. With ozone, registration is not required because it is a GRAS compound, so oranges can now be fumigated to eliminate thrips from the commodity without using methyl bromide. Also, it has been shown that Timothy hay can be successfully treated for Hessian fly in compressed bales using phosphine along with compression. Thus, two new export treatments are now available for use on commodities. Success using controlled atmosphere technology to control insects on harvested leafy vegetables has been encouraging and might lead to treatments that are efficacious and maintain quality. This success has shown vegetable export industry and scientific community the potential of controlled atmosphere technology to solve postharvest pest problems. In addition, by showing that walnut husk fly is unlikely to infest peaches and nectarines, a large market has been opened in Chile for exports of that stonefruit. Hawaiian commodities are often subject to quarantine treatments because of the fruit fly problems in Hawaii. Technology to replace methyl bromide as a quarantine agent has advanced in the areas of heat/cold and irradiation treatments of commodities from Hawaii resulting in the expansion of export markets for Hawaiian exotic fruits. Irradiation treatments have now been developed that will allow the U.S. to treat for apple maggot, plum curculio and oriental fruit moth in commodities being exported to such countries as Brazil. Finally, systems-approach technology is now allowing the export of commodities such as cherries to markets previously only open to methyl bromide fumigated commodities.

Problem Area IIc - Technology to capture/recycle methyl bromide used in postharvest fumigations to reduce or eliminate emissions to the atmosphere.

Outcomes, Goals, and Commitments: Critical goals for this problem area were to develop and refine technology to capture/recycle methyl bromide, which has been developed and refined, and is acceptable to EPA.

Selected Accomplishments: Extensive studies on the use of activated carbon to sorb methyl bromide following use in a commodity fumigation has resulted in 3 commercial units being installed in Texas and California. The sorption system removes methyl bromide from the exhaust stream from a fumigation chamber without interfering with the fumigation of the commodity in any way. This technology is capable of reducing the emission of free methyl bromide from a chamber following fumigation by approximately 89% (1,2). Because the carbon sorbs all of the methyl bromide until 5ppm remains in the chamber, there are no high concentrations of the fumigant emitted during the first 15 minutes of aeration as occurs in normal aeration where no capture is conducted.

Impact: The technology developed has been transferred to APHIS and to commercial export companies. This technology allows the fumigation of commodities with methyl bromide even in sensitive areas where emissions would be controlled by pollution abatement districts and other regulators. It alleviates the problem of large amounts of methyl bromide being emitted into the atmosphere in the first 15 minutes of aeration following a fumigation and changes the dynamics of the plume of fumigant being emitted. By changing plume dynamics, capture may provide a method to avoid buffer restrictions for methyl bromide or other fumigants.

Problem Area IId - Physical or chemical detection systems for stored product and quarantine pests.

Outcomes, Goals, and Commitments: Critical goals for this problem area were to develop physical or chemical detection systems for stored product and quarantine pests. Methods for detecting pests in stored commodities have been developed.

Selected Accomplishments: Research has demonstrated the efficacy of trap-lure designs for the detection and surveillance of invasive fruit fly species (1). Methods to identify intercepted larvae in fruit were published in a manual entitled "Handbook for Identification of *Anistrepha* Fruit Flies of Texas & Northern Mexico". This manual is now used by USDA-APHIS personnel to identify specimens recovered in border interceptions and from fruit fly surveillance trapping. This manual has been put onto CD and is an attacnment for the New Pest Response Guidelines (NRPG) for *Anistrepha* spp. by the USDA-APHIS-PPQ Pest Detection and Management Program, Riverdale, Maryland.

In quite a different application, ARS scientists have developed a grain probe that can be used in grain storage bins to monitor insect activity remotely on a computer (2). This system, originally called "EGPIC" and now sold under the name "Insector", counts and identifies insects that fall into a probe trap buried in a grain mass. This system allows facility managers to make early decisions about when to turn grain or treat it before damage occurs. This research fills a great void in grain storage by allowing hidden insect populations to be detected early and be treated. It also will give scientists a better understanding about how insects in a grain mass move and if any areas of a grain mass are more susceptible to attack than others.

Impact: The clientele for a portion of the fruit fly detection and lure research is USDA-APHIS-PPQ (for domestic U.S. programs) and USDA-APHIS-IS (for foreign certification or eradication programs). PPQ programs are also run in coordination with state agencies such as CDFA (California), DPI (Florida), the Texas Department of Agriculture. Documentation for the newly developed trap designs provide scientific data for decision criteria in making trapping system changes.

On the other hand, the clientele for the grain probe research is the many managers of grain storage facilities along with scientists conducting work on the spatial behavior of insects in durable grain masses. Grain storage managers and milling facilities now have a technology that allows them to monitor large or small storage areas that previously needed to be probed, turned or treated to identify and solve insect infestation problems. This technology will allow the grain only to be treated when necessary.

Problem Area IIe - Replacements for fumigating food processing plants, flour and other mills, food storage facilities, and transportation carriers such as ships and railcars.

Outcomes, Goals, and Commitments: Critical goals for this problem area were to develop alternatives to methyl bromide for fumigating food processing plants, flour and other mills, food storage facilities and transportation carriers such as ships and railcars. System approaches that limit pest populations have been developed. New fumigants and protectant chemicals have been shown to be effective in reducing pests. Irradiation, as well as heat and controlled atmosphere treatments have been shown to be effective in specific situations. Alternative treatments for wood pallets have been developed and lower the potential for pests from this source.

Selected Accomplishments:

Aerosol Space Treatments

ARS scientists have conducted research evaluating the efficacy of aerosol treatments against stored-product insect inside mills, processing facilities, and food storage warehouses. This research has focused on filling gaps in knowledge about efficacy of both current aerosol products and newer systems that can target specific areas within a facility. A series of recent trials inside commercial sites were conducted, using different aerosol products, to control red flour beetle and confused flour beetle larvae and adults. The confused flour beetle was more tolerant to the evaluated aerosols, and systems that deliver a particle size of 15 to 20 microns seem to give more complete control. Results also show that application systems with separate timing systems for individual areas within a facility show potential for reducing the need for fumigations of the entire site.

Contact Insecticides

Contact insecticides are used as general surface treatments and as crack and crevice or spot applications to control insects in milling, processing, and warehousing facilities. New reduced-risk insecticides such as insect growth regulators (IGRs) can effectively control beetle and moth pests when used as surface treatments, and targeted controls to specific areas are being advocated as a possible alternative to whole-plant fumigations (2, 3).

Heating of Facilities

Working with heat in facilities, it was found that heat treatments might alleviate the use of methyl bromide in mills and storage facilities. However, different insect species and life stages vary in their response to heat, and acclimation to heat during the heating cycle may be important in mortality. In lab studies where red and confused flour beetles were gradually exposed to temperatures ranging between 120 to 130°F, the time required to kill beetles decreased (1).

Impact:

The results of ARS research show that aerosol application systems, particularly those that offer options for targeted control within specific areas, could replace some applications of methyl bromide. There are monitoring systems that can identify locations or sources of infestations, and aerosols can be used to eliminate areas of infestation before they spread to other locations within the facility. Many industrial sites have installed aerosol systems, and use of aerosols, along with other management tactics, show potential for inclusion into an overall management strategy that reduces the need for methyl bromide fumigations.

Crack and crevice treatments may help reduce the number of whole-plant fumigations required in a processing plant or storage facility by keeping indigenous populations to a minimum. It may be rather easy to get registrations for some of these new control agents such as IGRs.

Problem Area IIf - Emergency technology that will allow movement of commodities out of emergency quarantine areas caused by accidental introduction of exotic pests such as fruit flies.

Outcomes, Goals, and Commitments: Critical goals for this problem area were to develop emergency technology to replace methyl bromide to allow movement of commodities out of emergency quarantine areas caused by accidental introduction of exotic pests such as fruit flies. New fumigants and protectant chemicals have been tested and efficacies determined. The logistics of using radiation on a commercial scale have been investigated, and a method has been developed to show the irradiated insects cannot reproduce. The use of heat and controlled atmospheres has been examined in commercial scale studies. Commercial-scale studies have determined the feasibility of heat and controlled atmospheres to control pests. Alternative treatments for wood pallets have been developed.

Selected Accomplishments:

Behavioral Studies

The West Indian fruit fly, *Anastrepha oblique* is an exotic pest which on occasion is found in surveillance traps in the southern United States. This fly apparently attacks dooryard fruit such as guava, plum and rose-apple in subtropical areas of Florida and Texas. Because its host range is incompletely known, its detection triggers quarantine restrictions, including a requirement for methyl bromide fumigation. Studies of this species behavior concerning host selection and survival of eggs and larvae in citrus showed that under laboratory conditions only late season (after mid-April) red varieties of grapefruit allow any development of adults. Females will oviposit in grapefruit after color break but egg mortality is 100% until after mid April and normally after seeds in the fruit begin to sprout. Hence, host utilization of this species is so limited that it does not pose a significant threat to U.S. citrus (1).

Physical Controls

In California a new pest which attacks olives, the olive fruit fly, has become established in the coastal portions of southern California. A cold treatment of 0-1°C for 2 weeks was found to provide a high level of post-harvest pest control for these flies. It has also been found that the climate of the San Joaquin Valley is not conducive to the spread of the olive fruit fly into that area where olives are a major product in California. Work by ARS scientists has also shown that infestation by transported olives from growers to processing areas can be prevented by transporting in brine (2).

Impact: The new information on West Indian fruit fly host relations was used by APHIS-PPQ to support revision of the absolute quarantine placed on grapefruit during outbreaks. Cold temperature treatments of harvested olives provide a non-chemical alternative to methyl bromide fumigation. Major beneficiaries of this research are fruit producers and packers since there is a reduction in the quarantine actions, including methyl bromide fumigation, often required when the pests are detected.

Problem Area IIg - Methods to prevent the spread of quarantine pests into and within the United States including population suppression, trapping and surveillance, and eradication

Outcomes, Goals, and Commitments: Critical goals for this problem area were the development of methods to prevent the spread of quarantine pests into and within the United States including population suppression, trapping and surveillance, and eradication. Better methods for detecting pests, use of a systems approach involving a combination of new technologies to limit pest populations and alternative fumigants and protectant chemicals have been shown to reduce potential spread of quarantine pests.

Selected Accomplishments:

Sterile Insect Release

The sterile insect technique (SIT) is used to suppress outbreak populations of the medfly. Improvements in this technology include the development of genetic sexing strains so that only males are released, the implementation of an aromatherapy strategy which enhances the competitiveness of the sterile males, and the advent of better lab diets that yield significant cost savings in the mass production of the sterile flies (16). Similarly, transgenic methods have been developed to produce male-only strains of lepidopteran fruit pests with similar benefits in efficacy and cost (3, 15).

Management techniques were developed and implemented based on knowledge of pest population dynamics allowing integration of biological control methods (such as SIT or augmentation of natural enemies) with pesticides (7,9,20). Among these advances was research which revealed the relationship between climate and population growth of the olive fly in California and the Mexican fruit fly in Texas . In Hawaii a pilot program demonstrated the effectiveness of integrated pest management programs against the fruit fly complex in melon and persimmon cropping systems (14,19,20).

Insecticide Baits

Through a cooperative agreement with Dow AgroSciences, an insecticidal bait was developed by ARS scientists using spinosad as the insecticide (14,21,22). This formulation (GF-120) is now registered for use in the U.S. and most fruit producing countries against tropical and temperate fruit flies (10,14). A modification of this bait was developed and was registered as organic by USDA and European certification agencies. This bait-spray system provides an alternative to malathion or other organophosphate based sprays for both emergency and management programs against fruit flies and can be used in organic production systems (13).

Synthetic lures have been identified as substitutes for the liquid protein baits that are traditionally used in *Anastrepha* fruit fly traps. Field tests have determined the best combinations against different species while reducing non-target effects which impact operation and maintenance of the surveillance traps (1,4,11,21,22). Slow-release technologies have extended the life of attractant devices thus increasing their cost-effectiveness.

Prohibition of Imports

Collaboration between ARS and APHIS-PPQ related to identification of risks associated with imported commodities documented that hot chili peppers (*Capsicum pubescens*) imported from Mexico were an uncontrolled pathway for Mexican fruit flies to the U.S. Certain varieties of hot peppers require shade and are intercropped with fruit trees, a factor contributing to their infestation risk. As a consequence, imports of these varieties have been prohibited (18).

Impact: The agricultural community, including research scientists, growers, and especially sterile fruit fly program officials, have several new weapons at their disposal to improve the efficacy and reduce costs of sterile insect releases and other eradication programs worldwide. In Hawaii, growers have completely taken over demonstration programs for fruit fly pest management in persimmon and melons. The new fruit fly suppression technologies have resulted in a drastic reduction in the use of organophosphate insecticides. Fruit fly outbreaks have been eradicated in Florida, Texas, and California using GF-120 in place of the malathion previously used. After forbidding the use of malathion sprays, Mexico and Guatemala have allowed the MoscaMed program to resume sprays over more than 300,000 hectares with GF-120. New improved trap-lure systems are currently being used by California, Florida and Texas action agencies for detecting invasive fruit fly species and by MoscaMed for fruit fly monitoring in Mexico and Guatemala. A patent for “attract and kill” devices has been filed (Heath, R. R. Baiting system for suppressing populations of insects such as Mediterranean and Caribbean fruit flies).

APPENDIX 1 – SELECTED SUPPORTING INFORMATION AND DOCUMENTATION FOR ACCOMPLISHMENTS AND IMPACT OF NP 308 RESEARCH

Component II: Postharvest Commodity Treatment (Including Structural)

Problem Area IIa: Methodologies to maintain quality of stored durable commodities

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Problem Area IIc: Technology to capture/recycle methyl bromide used in postharvest fumigations to reduce or eliminate emissions to the atmosphere.

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Problem Area IId: Physical or chemical detection systems for stored product and quarantine pests.

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2. Schuman, D., Weaver, D. K., and Larson, R. G. 2005. Performance of an analytical, dual infrared-beam, stored-product insect monitoring system. J. Econ. Entomol. 98: 1723-1732.

<u>Problem Area IIe: Replacements for fumigating food processing plants, flour and other mills, food storage facilities, and transportation carriers such as ships and railcars.</u>

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<u>Problem Area IIf: Emergency technology that will allow movement of commodities out of emergency quarantine areas caused by accidental introduction of exotic pests such as fruit flies.</u>

1. Thomas, D.B, T.C. Holler, R.R. Heath, E. Salinas, and A. Moses. 2001. Trap-lure combinations for surveillance of *Anastrepha* fruit flies (Diptera: Tephritidae). Florida Entomol. 84:344-349.

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<u>Problem Area IIg: Methods to prevent the spread of quarantine pests into and within the United States including population suppression, trapping and surveillance, and eradication.</u>

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3. Frantisek M., L.G. Neven, A.S. Robinson, M Vreysen, M.R Goldsmith, J. Nagaraju, and G. Franz, 2005. Development of genetic sexing strains in Lepidoptera: From traditional to transgenic approaches. J. Econ. Entomol. 98: 248-259.

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11. Moreno, D. S. and Mangan, R. L. 2002. Bait Matrix for Novel Toxicants for Use in Control of Fruit Flies (Diptera: Tephritidae). Pp. 333-362. *In*: Hallman, G. and Schwalbe, C. P. (eds.), Invasive Arthropods in Agriculture. Problems and Solutions. Science Publishers, Inc. Enfield, NH. 447 pp.

12. Moreno, D. S., Harris, D. L. Burns, R. E., and Mangan, R. L. 2002. Novel chemical approaches for the control of fruit flies in citrus orchards. Proceedings of 9th International Conference of the International Society of Citriculture. pp. 3-7.

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15. Rendon, P., D. O. McInnis, D. Lance, and J. Stewart. 2004. Medfly (Diptera: Tephritidae) genetic sexing: Large-scale field comparison of males-only and bisexual sterile fly releases in Guatemala. J. Econ. Entomol. 97: 1547-1553.

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APPENDIX II – MAJOR RESEARCH PARTNERS, COOPERATORS, AND/OR RESEARCH/SERVICE NETWORKS

Component II: Postharvest Commodity Treatment (Including Structural)

Problem Area IIa: Methodologies to maintain quality of stored durable commodities.

Individual Cooperators:

ARS:

R. T. Arbogast, USDA ARS, Gainesville, FL
F. H. Arthur, USDA ARS, Manhattan, KS: Chemical control tactics
J. F. Campbell USDA-ARS, Manhattan, KS:
J. D. Hansen, USDA-ARS, Yakima, WA.
L. A. Lacey, USDA-ARS, Yakima, WA.
M. A. Mullen, USDA ARS, Manhattan, KS (retired)
D. Toews, USDA ARS, Manhattan, KS

Non-ARS:

R. Fritts, Certis USA, Columbia, MD
B. S. Higbee, Paramount Farming Co. Bakersfield, CA
J. E. McGovern, Orkin Commercial Division, Atlanta, GA
E. J. Mitcham, Coop. Ext. University of California, Davis.
S. Prabhakaran, Dow AgroSciences LLC, Indianapolis, IN
J. Tang, Washington State University, Pullman
S. Wang. Washington State University, Pullman

Organizational Cooperators:

AgriVir LLC, Falls Church, VA
Walnut Marketing Board of California

Problem Area IIb: Quarantine treatments for export of commodities and provision of technical assistance to APHIS to gain acceptance of these procedures by trading partners.

Individual Cooperators:

ARS:

Louis Aung, USDA-ARS-SJVASC, Parlier, CA (retired)
Stephen Drake, USDA-ARS, Wenatchee, WA
P. Follett, USDA, ARS, Hilo, HI
Guy Hallman, USDA-ARS, Weslaco, TX
R. Hollingsworth, USDA, ARS, Hilo, HI
Judy Johnson, USDA-ARS, Parlier, CS
J. Leesch, USDA, ARS, Parlier, CA
T, McHugh, USDA, ARS, Albany, CA
L. Neven, USDA, ARS, Wapato, WA

David Obenland, USDA-ARS-SJVASC, Parlier, CA
Fred Ryan, USDA-ARS-SJVASC, Parlier, CA
Krista Shellie, USDA-ARS, Parma, ID
Joseph Smilanick,USDA-ARS-SJVASC, Parlier, CA
D. Street, USDA, ARS, Stoneville, MS
M. Wall, USDA, ARS, Hilo, HI

Non-ARS:
Juming Tang, WSU, Pullman, WA
Dan Black, Techni-Systems, Chelan, WA
Harold Ostenson, Stemilt Growers, Wenatchee, WA
Jim Archer, Northwest Fruit Exporters, Yakima, WA
James Christie, Bryant-Christie, Inc., Sacramento, CA
Mike Willett, Northwest Horticultural Council, Yakima, WA
Dr. Elizabeth Mitcham, University of California at Berkeley, CA
Jim Culbertson, California Cherry Advisory Board, Lodi, CA
R. Paull, University of Hawaii at Manoa

Organizational Cooperators:
California and Arizona Lettuce Export Council (CALEC)
California Almond Board
California Cherry Advisory Board
California Citrus Research Board
California Dept. of Food & Agriculture
California Dried Plum Advisory Board
California Dried Plum Bargaining Board
California Energy Commission
California Olive Committee
California Pistachio Commission
California Table Grape Commission
California Tree Fruit Agreement
Cosmed Group, Inc.
Florida Dept. of Agriculture & Consumer Services
Food Technology Services, Inc.
Hawaii Banana Industry Association
Hawaii Papaya Industry
Hawaii Pride
Hawaii Sweetpotato Industry
Hawaii Tropical Fruit Growers
Mexican Mango Exporters (EMEX)
National Hay Association
Suterra, LLC
TransFresh Corporation
Walnut Marketing Board
Washington Tree Fruit Research Commission
Washington State Commission on Pesticide Registration

USDA-APHIS, Riverdale, MD

Problem Area IIc: Technology to capture/recycle methyl bromide used in postharvest fumigations to reduce or eliminate emissions to the atmosphere.

Individual Cooperators:

ARS:

J. G. Leesch, USDA-ARS-SJVASC, Parlier, CA
J. D. Snyder, USDA-ARS-HCRL, Fresno, CA (no longer in ARS)
B. E. Mackey, USDA-ARS-PWA, Albany, CA

Non-ARS:

Gary Knapp, Engineer, G.F.K. Consultants Limited, Inc.
Gary Jue, Valley Fig Corperation
Dr. David McAllister, Great Lakes Chemical Corp.
Scott Wood, USDA, APHIS, PPQ, Raleigh, NC
Peter Weatherall, USDA, APHIS, PPQ, Raleigh, NC (retired)

Organizational Cooperators:

Great Lakes Chemical Corporation
G.F.K. Consultants Limited, Inc.
Valley Fig Corporation
Well-Pict Corporation
USDA, APHIS, PPQ
Port of San Diego, CA

Problem Area IId: Physical or chemical detection systems for stored product and quarantine pests.

Individual Cooperators:

ARS:

R. T. Arbogast, USDA-ARS, Gainesville, FL
N. D. Epsky, USDA-ARS, Miami, FL
R. R. Heath, USDA-ARS, Miami, FL

Non-ARS:

T. C. Holler, USDA-APHIS, Gainesville, FL
D. K. Weaver, Dept. Entomol., MontanaState Univ., Bozeman, MT

Organizational Cooperators:

California CDFA,
Florida DPI
Texas Dept. of Agriculture
OPIsystems, Inc., Calgary, Canada

Problem Area IIe: Replacements for fumigating food processing plants, flour and other mills, food storage facilities, and transportation carriers such as ships and railcars.

Individual Cooperators:

ARS:

J. F. Campbell, USDA ARS, Manhattan, KS
M. D. Toews, USDA ARS, Manhattan, KS

Non-ARS:

Mr. Shiva Mohandass, former graduate student
Ms. Emily Jenson, current graduate student

Organizational Cooperators:

Entech Corporation, Kenner, LA

Problem Area IIf: Emergency technology that will allow movement of commodities out of emergency quarantine areas caused by accidental introduction of exotic pests such as fruit flies.

Individual Cooperators:

ARS:

R. R. Heath, USDA-ARS, Miami, FL

Non-ARS:

E. Burns, FLDACS/DPI, Gainesville, FL
Walter Enkerlin, UN/IAEA Vienna, Austria
J. Fisher, Suterra LLC, Bend, OR
Gerald Franz, IAEA-FAO
Iva Fukova, Institute of Entomology, Academy of Sciences of the Czech Republic
Marian Goldsmith, University of Rhode Island
Jorge Hendrichs, UN/IAEA, Vienna, Austria
T. Holler, USDA/APHIS, Gainesville, FL
Frantisek Marec, Institute of Entomology, Academy of Sciences of the Czech Republic
Dr. Ronald Mau, University of Hawaii at Manoa,
J. Nagaraju, Centre for DNA Fingerprinting and Diagnostics, India
Dr. Pedro Rendon (USDA/APHIS/CPHST), MoscaMed Programm Guatemala City, Guatemala.
Alan S. Robinson, IAEA-FAO
Dr. Todd Shelly (USDA/APHIS/CPHST)
Marc Vreysen, IAEA-FAO
Dr. Lyle Wong, Hawaii Department of Agriculture

Organizational Cooperators:

California Olive Committee

California Citrus Research Board
Dow AgroSciences
USDA-APHIS-IS
USDA-APHIS-PPQ
Washington Tree Fruit Research Commission
Washington State Commission on Pesticide Registration

Problem Area IIg: Methods to prevent the spread of quarantine pests into and within the United States including population suppression, trapping and surveillance, and eradication.

Individual Cooperators:

ARS:

P.E.A. Teal, USDA/ARS, Gainesville, FL
J. Sivinski, USDA/ARS, Gainesville, FL
R. Mangan, USDA/ARS, Weslaco, TX
D. Thomas, USDA/ARS, Weslaco, TX

Non-ARS:

W. Enkerlin, J. Hendrichs, UN/IAEA, Vienna, Austria
J. Fisher, Suterra LLC, Bend, OR
E. Burns, FLDACS/DPI, Gainesville, FL
T. Batkin, California Citrus Research Board
T. Holler, USDA/APHIS, Gainesville, FL
Ronald Mau, University of Hawaii at Manoa
Lyle Wong, Hawaii Department of Agriculture

Organizational Cooperators:

California Citrus Research Board
Suterra, LLC
UN/IAEA, Vienna, Austria

APPENDIX III – RESEARCH PROJECTS

Location	Project Number and Title	Scientists (P= Principal Investigator)	Project Start Date
California			
Davis	# 5306-22000-013-00D, Etiology and Biology of Diseases Affecting Deciduous Fruit/Nut Trees, Grapevine, Oak Trees, and Strawberries	Kluepfel, Daniel A. (P) Uyemoto, Jerry K. Browne, Greg T. 1 Vacant	8/01/2004
Parlier	# 5302-21220-004-00D, Improvement of Prunus and Vitis Scion and Rootstocks for Fruit Quality and Pest Resistance	Craig Ledbetter (P) Ramming, David W.	8/01/2003
	# 5302-13220-003-00D, Alternatives to Methyl Bromide for Strawberry Ornamental, Vine, and Tree Crop Systems in California	Schneider, Sally M. (P) Gerik, James S. Trout, Thomas J. Gao, Suduan 1 Vacant	5/17/2003
	# 5302-43000-028-00D, Develop Postharvest Chemical and Non-Chemical MB Alternatives for Quality Maintenance of Fresh California Grown Commodities	Obenland, David M. (P) Smilanick, Joseph L.	11/13/2002
	# 5302-43000-030-00D, Chemically Based Methods as Alternatives to Methyl Bromide for Postharvest and Quarantine Pests	Leesch, James G. (P) Burks, Charles S. Yokoyama, Victoria Kuenen, Lodewyk P.S. Johnson, Judy A. 1 Vacant	1/11/2003
	# 5302-43000-031-00D, Alternatives to Chemical Control for Stored Product and Quarantine Pests of Fresh/Dried Fruits and Nuts	Leesch, James G. (P) Johnson, Judy A. Siegel, Joel P. Kuenen, Lodewyk, P. S. Yokoyama, Victoria Burks, Charles S. Leopold, Roger A. 2 Vacants	5/10/2003
Riverside	# 5310-12130-007-00D, Minimizing Air and Water Contamination from Agricultural Pesticides	Yates, Scott R. (P) Skaggs, Todd H. 1 Vacant	5/16/2002
Salinas	# 5305-43000-002-00D, Disinfest Lettuce of Insects Through Postharvest Treatments and Pre-Harvest IPM	Yong, Biao Liu (P)	12/10/2002
	# 5305-22000-009-00D Control of Pathogens in Strawberry and	Martin, Frank N. (P) Bull, Carolee T.	7/1/2003

	Vegetable Production Systems	1 Vacant	
Florida			
Gainesville	# 6615-12000-003-00D, Improving Efficacy of Fumigants by Promoting Uniform Dispersion in Soil and Minimizing Emissions to the Atmosphere	Allen, Jr., Leon H. (P) Vu, Joseph C Chourey, Prem S.	12/17/2002
Fort Pierce	# 6618-22000-029-00D, Alternatives to Methyl Bromide Soil Fumigation for Vegetable and Floriculture Production	Chellemi, Daniel O. (P) Burelle, Nancy K. Church, Gregory T. Rosskopf, Erin N.	2/26/2004
Miami	# 6631-22000-003-00D, Protection of Subtropical and Tropical Agriculture Commodities and Ornamentals from Exotic Insects	Epsky, Nancy D. (P) Heath, Robert R. Kendra, Paul E.	10/31/2003
Georgia			
Byron	# 6606-22000-012-00D, Nematode and Disease Management of Deciduous Fruits	Nyczepir, Andrew P.	3/6/2003
Tifton	# 6602-21220-011-00D, Management of Plant-Parasitic Nematodes in Agronomic, Vegetable, and Forage Crops Grown in the Southeast	Timper, Patricia (P) Davis, Richard F. Lewis, Wallace J.	1/14/2003
	# 6602-22000-032-00D, Integrated Management and Ecology of Weed Populations in the Southeastern Coastal Plain	Johnson, Wiley C. (P) Webster, Theodore M. Lewis Wallace John	10/1/2000
Hawaii			
Hilo	# 5320-22430-019-00D, Rearing and Release Technology for Biological Control and Sterile Insect Releases of Fruit Flies	McInnis, Donald O. (P) Chang, Chiou Ling Gonsalves, Dennis	6/3/2005
	# 5320-22430-021-00D, Detection, Control and Area-Wide Management of Fruit Flies	Vargas, Roger I. (P) McQuate, Grant T. Harris, Ernest J. Jang, Eric B. Gonsalves, Dennis	3/30/2005
	# 5320-43000-014-00D, Postharvest Treatment of Tropical Commodities for Quarantine Security, Quality Maintenance, and Value Enhancement	Armstrong, John W. (P) Hollingsworth, Robert Wall, Marisa M. Follett, Peter A. Gonsalves, Dennis	4/28/05
Kansas			
Manhattan	# 5430-43000-027-00D, Ecology, Sampling, and Modeling of Insect Pests of Stored Grain, Processing	Flinn, Paul (P) Campbell, James F. Throne, James R.	4/28/2005

	Facilities, and Warehouses		
	# 5430-43000-025-00D, Integrated Management of Insect Pests in Stored Grain and In Processed Grain Products	Arthur, Frank (P) Lord Jeffrey C. Baker, James E.	4/6/2005
Maryland			
Beltsville	# 1265-21220-176-00D, Biological Technologies as Alternatives to Chemicals for Control of Soilborne Plant Pathogens	Roberts, Daniel P. (P) Abdul Baki, Aref A. Millner, Patricia	11/13/2002
	# 1275-22000-203-00D, Microbes, Natural Products, and Amendments for Management of Plant-Parasitic Nematodes	Meyer, Susan (P) Chitwood, David J. Zasada, Inga A.	2/25/2003
	# 1230-22000-018-00D, Alternatives to Methyl Bromide for Management of Soilborne Pathogens in Ornamental Crops	Lakshman, Dilip K. (P)	9/15/2005
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