United States Department of Agriculture

Research, Education, and Economics

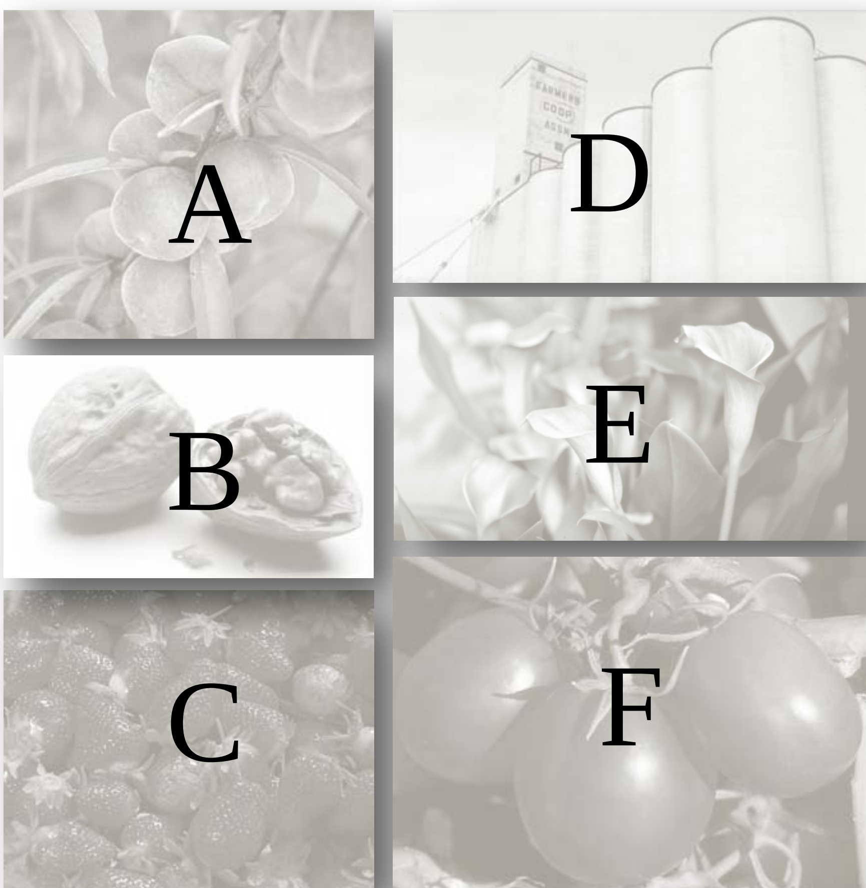
AGRICULTURAL RESEARCH SERVICE

Office of National Programs

SEPTEMBER 2011

National Program 308: Methyl Bromide Alternatives

Accomplishment Report 2006-2011



A: Alternatives to methyl bromide are now used to manage replant diseases in some orchards and vineyards. Research to improve these alternatives and discover additional ones is ongoing. Photo by Keith Weller, ARS.

B: Although progress has been made, improved alternatives are still needed for exported crops that are marketed soon after harvesting. Photo by ARS.

C: While research continues to improve existing methyl bromide alternatives and seek new ones, integrated systems have allowed successful production on more than 60 percent of California strawberry acreage without the use of methyl bromide. Photo by Ken Hammond, ARS.

D: New fumigants are now available to manage insects in postharvest food-processing facilities, but may be subject to regulatory constraint. Research seeks to find additional alternatives to methyl bromide. Photo by Peggy Greb, ARS.

E: Some progress has been made in developing methyl bromide alternatives for ornamental crop production systems, which are especially challenging due to small acreages, large diversity of crops, and cropping cycles that are often short. Photo by Jim Gerik, ARS.

F: Under some circumstances, chemical, biological, and cultural methods for soil pest control can be used in place of methyl bromide in vegetable production systems. Research to expand the use of these alternatives and to improve and seek new methyl bromide alternatives continues. Photo by Peggy Greb, ARS.

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National Program 308: Methyl Bromide Alternatives ACCOMPLISHMENT REPORT 2006-2011

BACKGROUND AND GENERAL INFORMATION

This report is a distillation of some of the most significant research accomplishments from the USDA, Agricultural Research Service (ARS) National Program (NP) 308, Methyl Bromide Alternatives, over the past 5 years. Research in NP 308 focuses on discovery and development of alternatives to methyl bromide in two broad areas of research—preplant soil fumigation to control pests, pathogens and nematodes, and weeds, and postharvest fumigation to protect harvested crops from pests during storage, including disinfesting structures in which commodities are processed or stored.

The mission of NP 308 is to develop environmentally compatible and technically and economically feasible alternatives to the use of methyl bromide for preplant soil fumigation and as a postharvest commodity treatment. This national program supports U.S. compliance with the Montreal Protocol, an international treaty, and provides scientific knowledge for regulatory agencies and new technologies for producers impacted by regulations such as the Clean Air Act.

Because of the wide range of pathogens and pests managed with methyl bromide, there is no single replacement for methyl bromide, but rather combinations of approaches, which are often developed for specific commodities or uses. While NP 308 research centers on finding, developing, and/or improving materials and technologies that can be readily adopted by industry as alternatives to methyl bromide, research on fundamental aspects of disease and pest detection, identification, and management are also conducted to optimize performance of methyl bromide alternatives.

NP 308 was initiated after methyl bromide was listed as a stratospheric ozone depletor by the Parties to the Montreal Protocol (Parties) in 1992. The Parties agreed to freeze production levels of methyl bromide for developed countries at 1991 levels in 1995 and to a complete phase-out later on. In developed countries, complete phase-out of manufacturing and importation of methyl bromide occurred on January 1, 2005, except for quarantine/pre-shipment (QPS) uses and Critical Use Exemptions (CUEs), which are granted on a case-by-case yearly basis. Although no decision was taken by the Parties to regulate QPS uses, research on the development of new alternatives to replace methyl bromide as a quarantine fumigant is included in the postharvest component of NP 308.

CUEs are granted by the Parties when a technically and economically feasible alternative is not available to replace methyl bromide for a specific crop or commodity use, and significant market disruption would occur with the loss of methyl bromide. A criterion for consideration of a CUE is an active research program to find methyl bromide alternatives. NP 308 contributes to U.S. compliance with this criterion. By the start of the 5-year program cycle in 2006, significant reductions in methyl bromide use had been made, compared to the 1991 baseline, but for some uses and some circumstances adequate alternatives had not been identified, developed, received regulatory approval, and marketed. CUEs have been granted to the United States and other developed countries for a variety of agricultural sectors, both preplant and postharvest, including tomatoes, strawberries (fruiting fields and nurseries), peppers, eggplant, floriculture, perennial field nurseries, orchard and vineyard replant, flour mills, bakeries, food processors, traditional ham curing, and the preservation of historical artifacts.

While the problem of finding affordable, effective, and environmentally acceptable alternatives to methyl bromide has not been completely solved, progress has been made. Alternative chemistries have been identified and evaluated for preplant use in annual, perennial, and nursery cropping systems, and alternative application technologies and non-chemical control strategies have been developed.

Growers' experience with potential alternatives for preplant use of methyl bromide has shown that the efficacy of some alternative treatments declined in each successive year, indicating the need for additional, commercial-scale, multi-year evaluations of methyl bromide alternatives. To address this need, in addition to the appropriated, longer-term research projects in NP 308, a 5-year Areawide Pest Management (AWPM) Project for Methyl Bromide Alternatives (MBA) was established in fiscal year 2007. AWPM projects are centered on the utilization of ARS developed technologies (biological, cultural, physical, and chemical) in an integrated pest management (IPM) approach to effectively manage pests impacting large areas spanning multiple states or regions. The MBA-AWPM project focuses on fruit, vegetable, and floral/nursery crop production areas in the western and southeastern United States. The MBA-AWPM project is conducted through collaborations among ARS scientists and representatives from universities and industry groups. In addition, the project has commercial growers, technical and management representatives from agricultural service industries, and commodity group representatives as active participants. The objectives of the MBA-AWPM project are to demonstrate integrated alternatives to methyl bromide for the control of soilborne pests and weeds that:

- Contribute to sustained economic competitiveness;
- Result in reduced environmental impacts; and
- Increase farm worker safety.

There have been significant declines in the use of methyl bromide for postharvest uses, especially for durable commodities, such as raisins, where the need for quick treatment is not critical. Significant research needs remain for commodities that are marketed soon after harvest to meet critical markets, such as walnuts for the holidays. Some alternatives are perceived as working too slowly to be acceptable to the industry and other, more rapid treatments, have regulatory and efficacy issues that preclude full adoption by the industry. Further research into IPM approaches can help reduce reliance on methyl bromide for structural fumigation and augment the efficacy of alternative fumigants.

In addition to alternatives to methyl bromide for uses allowed by CUEs, ARS conducts research to find alternatives for QPS use of methyl bromide not currently controlled by the Montreal Protocol. Reliance on one particular fumigant for QPS use is not prudent and ARS is committed to finding methyl bromide alternatives to avoid possible future disruption of trade. Effective quarantine treatments are very important to maintaining international trade and preventing the spread of quarantine pests that can devastate a country's agriculture and natural resource assets. On the export side, methyl bromide is important to maintaining many foreign markets for U.S. commodities, where quarantine issues prevent shipment without methyl bromide fumigation. On the import side, many commodities shipped to the United States enter only after mandatory methyl bromide fumigation. Even when there is no mandatory fumigation, commodities may still be fumigated if inspections reveal quarantined pests. Furthermore, methyl bromide fumigation of solid wood packaging to prevent the introduction of exotic forest pests into the United States has become more prevalent.

Alternative treatments for quarantine use have been developed for a number of commodities that rely on methyl bromide for export clearance. These involve heat and modified atmospheres, alone or in combination, irradiation, cold, and alternative fumigants; but there is still great reliance on methyl bromide as the main tool to clear quarantined commodities for U.S. export to other countries as well as to treat quarantined commodities being imported into the United States.

Two AWPM projects contributed to reductions in postharvest methyl bromide use through their impact on the widespread control of insect pests. One project, the Areawide Control Program for Navel Orangeworm-Areawide Pest Management (NOW-AWPM) project, is centered on almonds, pistachios, and walnuts in California, while the other, Areawide Pest Management of Fruit Flies in Hawaii (FF-AWPM), was focused on fruit flies in commodities exported from Hawaii. The objective of both programs was to demonstrate and transfer to grower groups effective IPM technologies for the control of these insect pests; technologies that incorporate biological control, cultural control, reduced risk insecticides, and non-chemical methods.

Reductions in the amounts of methyl bromide nominated by the United States and approved by the Parties for CUEs, for several crop sectors, are indicators of successful development and implementation of methyl bromide alternatives. Similarly, crops for which CUE levels are still relatively high, clearly demonstrate that there are still challenges to the total phaseout of methyl bromide. Figure 1 shows the trends for selected preplant CUEs used predominantly in the southeastern United States. Figure 2 shows the trends for selected preplant CUEs used predominantly in the western United States. Figure 3 shows the trends for selected postharvest CUEs. ARS research, in collaboration with university and industry partners, plays a significant role in the transition of U.S. agriculture from the use of methyl bromide to alternatives and continues to address the remaining needs for efficacious and acceptable alternatives.

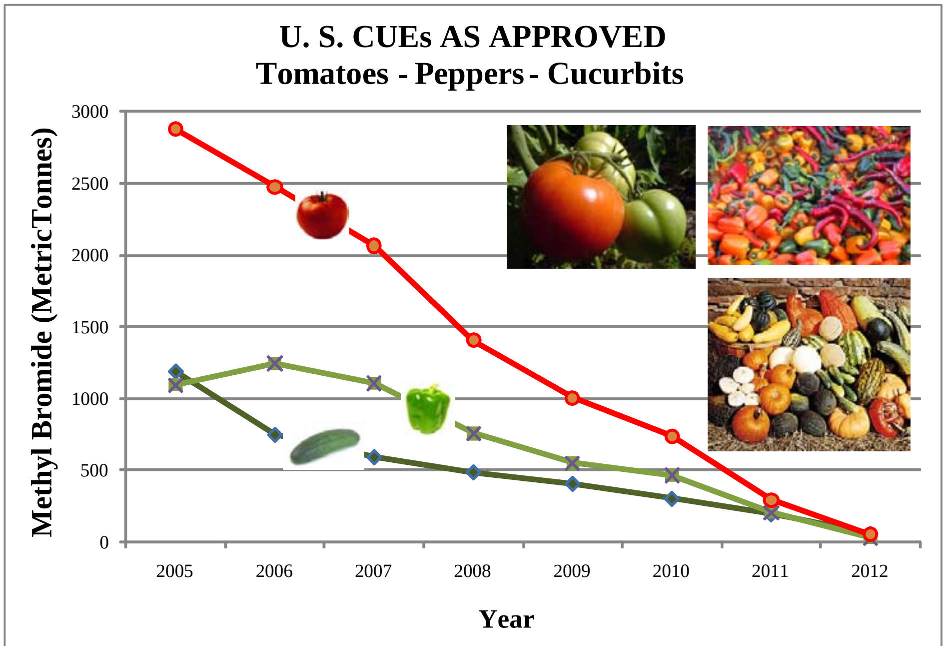

Figure 1. CUEs approved by the Parties for soil fumigation from 2005 to 2012 for tomatoes, peppers, and cucurbits grown in the southeastern United States.

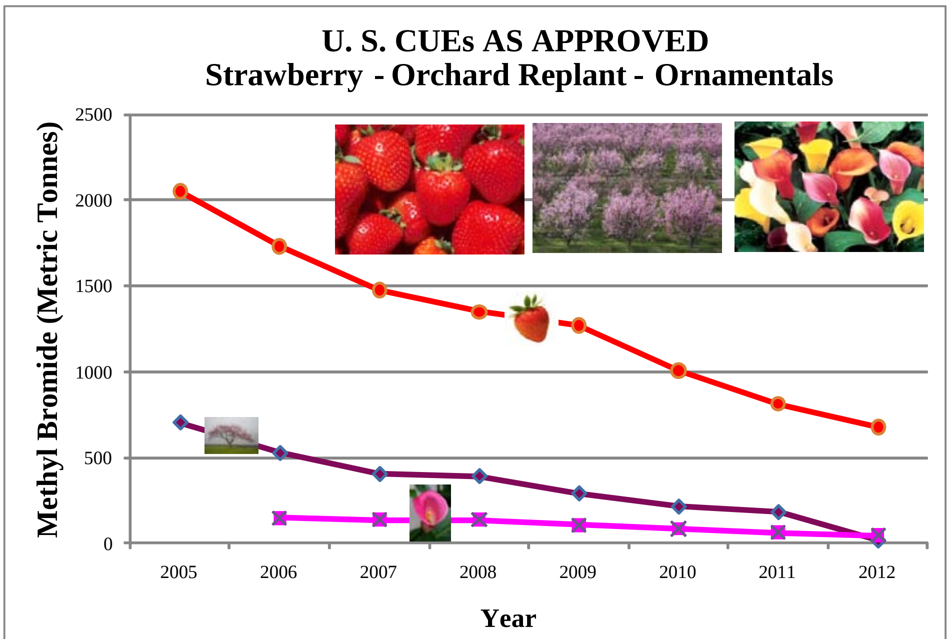

Figure 2. CUEs approved by the Parties for soil fumigation from 2005 to 2012 for strawberries, orchard/vineyard replant, and ornamental crops grown primarily in the western Unites States.

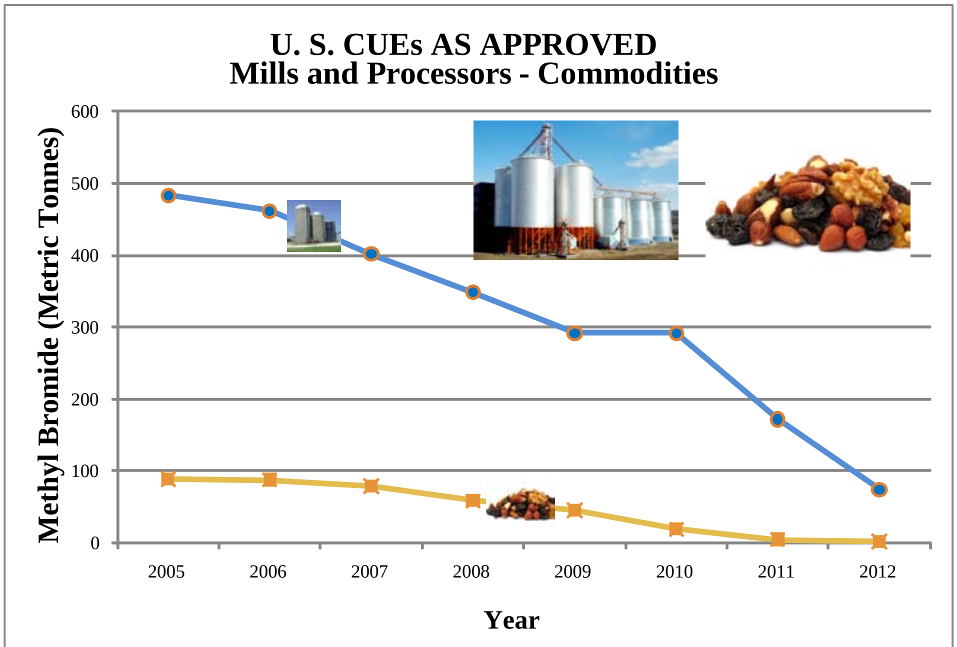

Figure 3. CUEs approved by the Parties for commodity fumigation from 2005 to 2012 for mills and processors as well as durable commodities.

PLANNING AND COORDINATION FOR NATIONAL PROGRAM 308

This 5-year cycle of NP 308 began with a Customer/Stakeholder Workshop in March 2006. ARS scientists and administrators met with customers, stakeholders, and research partners and identified major issues and research priorities in the transition to methyl bromide alternatives. At the Workshop, two major components for NP 308 were identified; they serve as the basis for the current NP 308 Action Plan, which can be viewed at: www.ars.usda.gov/research/programs/programs.htm?np_code=308&docid=14368

For the reader's convenience, information in the gray boxes that follow is taken directly from the NP 308 2007-2012 Action Plan.

Subsequent to the Customer/Stakeholder Workshop, the NP 308 Action Plan was drafted by a writing team composed of ARS scientists and National Program Leaders. The writing teams combined input from the customer workshop, their own knowledge of the science subject matter, and input from other ARS scientists and cooperators to identify the priority needs that could be addressed by ARS research. These individual research needs were aggregated into larger Problem Statements for each NP 308 Component. After a public comment period, the draft Action Plan was revised and completed in 2006, a plan which guided the development of new research project plans that began the new 5-year cycle in 2007.

All project plans for NP 308 included statements of the agricultural problem being addressed, the anticipated products or information to be generated by the project, how the planned research contributed to mitigating or solving the larger NP 308 problem statements, and time lines and milestones for measuring progress toward achieving the project's objectives. All project plans associated with NP 308 were then evaluated for scientific quality by external peer panels. Project plans were revised in response to review panel recommendations, and implemented. Project plans were approved for the period of 2007-2012.

Day-to-day coordination and planning of NP 308 are the tasks of the National Program Leaders who constitute the NP 308 leadership team. The team also coordinates NP 308 activities with other ARS National Programs and with other agencies and departments.

STRUCTURE OF NATIONAL PROGRAM 308

The NP 308 Action Plan is divided into two components and multiple problem statements as follows.

- **Component 1**: Preplant Soil Fumigation Alternatives
  - **Problem Statement 1A**: Development of New Technologies for Alternatives and Integration into Commercial Crop Production Systems Currently Dependent upon Methyl Bromide Soil Fumigation.
  - **Problem Statement 1B**: Pest Management Systems to Optimize Efficacy of Pesticides and Reduce Harmful Emissions.
  - **Problem Statement 1C**: Identification and Mitigation of Emerging Problems.
  - **Problem Statement 1D**: Lack of Commercial Scale Demonstrations of the Technical and Economic Feasibility of Currently Available Alternatives.

- **Component 2**: Postharvest Alternatives
  - **Problem Statement 2A**: Developing Alternatives to Methyl Bromide for Disinfestation of Postharvest Food Processing Facilities.
  - **Problem Statement 2B**: Develop Alternatives to Methyl Bromide for Disinfestation of Postharvest Durable Commodities.
  - **Problem Statement 2C**: Develop Alternatives to Methyl Bromide for Disinfestation of Postharvest Perishable Commodities.

HOW THIS REPORT WAS CONSTRUCTED AND WHAT IT REFLECTS

In this report, NP 308 achievements and their impacts are organized according to components and their constituent problem statements. The report first presents text from the current Action Plan which outlines the problem statements, research needs, and anticipated products for each of the components. These are followed by a summary of NP 308 accomplishments and impacts for each problem statement. Then, selected accomplishments are listed as examples of contributions toward the high priority needs identified by customer/stakeholders and described in the NP 308 Action Plan.

For the most part, the content of this report is derived from the 2006-2010 annual reports from NP 308 research projects. This report does not include all accomplishments achieved by this national program rather, only selected accomplishments that illustrate and exemplify the total progress and achievements at the national level.

NP 308 currently encompasses 16 research projects and 38 scientists. The relationship of NP 308 to the ARS Strategic Plan is outlined in Appendix I; research projects are listed in Appendix II; publications in peer-reviewed journals authored by NP 308 scientists are compiled in Appendix III; publications in the "Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions" are found in the Web links listed in Appendix IV; inventions and patents resulting from the research of NP 308 scientists are listed in Appendix V; and customer workshops and meetings are listed in Appendix VI.

This report was prepared for an external (to ARS) retrospective review of NP 308 to assess how well this national program attained its goals, as outlined in the current Action Plan. Accordingly, the purpose of the retrospective review is not to judge the performance of individual research projects, but rather to gauge the overall impact of NP 308. Consequently, the report does not attempt to catalogue all the accomplishments of the constituent research projects of NP 308. Individual scientists or projects are not identified by name in the narrative text; their achievements are described in the context of contributions to the national program's commitments to U.S. agriculture.

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COMPONENT 1: PREPLANT SOIL FUMIGATION ALTERNATIVES

Preplant soil fumigation with methyl bromide is used to control pests, plant pathogens and nematodes, weeds, and diseases of unknown causes, for many high-value crops including, strawberries, tomatoes, peppers, ornamentals, field-grown propagative materials, grapes, and fruit and nut trees. The phasing out of methyl bromide raised two major issues for growers using methyl bromide as a preplant soil fumigant.

The first is the need to quickly find effective, economically feasible alternative control strategies. Methyl bromide can be used effectively against a broad spectrum of soil pests over a range of soil types, temperatures, and moistures, resulting in greater flexibility and less risk of loss than is possible with many other soil management strategies. Most, if not all, potential methyl bromide alternative fumigants have a narrower spectrum of activity and/or a more restricted range of optimal soil conditions. As a result, growers will need to use their experience, soil analyses, crop consultants, or other resources to select an economically feasible and environmentally acceptable alternative that will be effective against the pest(s) in their fields, under the soil conditions found in that field. ARS is addressing this issue by evaluating new chemicals, host resistance, grafting to resistant rootstocks, soil amendments, biological control agents, mulches, crop rotation, fallow, suppressive soils, and new application technologies to deliver biological and chemical alternatives.

The second issue is to increase understanding of the pathogens and soil factors limiting crop production. A long-term, integrated management approach requires a thorough understanding of soil biological, chemical, and physical factors and their interactions and spatial variability to optimize chemical, genetic, biological, and cultural management strategies. The short-term solutions to methyl bromide alternatives are stepping stones to the longer term research to find integrated management systems that eliminate methyl bromide use for those crops that currently use it.

Engaged ARS Locations: Parlier, California; Salinas, California; Washington, D.C.; Fort Pierce, Florida; Gainesville, Florida; Beltsville, Maryland; and Wenatchee, Washington.

PROBLEM STATEMENT 1A: DEVELOPMENT OF NEW TECHNOLOGIES FOR ALTERNATIVES AND INTEGRATION INTO COMMERCIAL CROP PRODUCTION SYSTEMS CURRENTLY DEPENDENT UPON METHYL BROMIDE SOIL FUMIGATION.

Problem Statement: Four distinct crop production sectors currently rely on methyl bromide soil fumigation: plasticulture annual fruit and vegetable crops; annual ornamental crops; perennial crops; and nursery crops. Each of these sectors has to address different economic thresholds and different pest and disease complexes. For each sector, an integrated production system must consider all the soil biological, physical, and chemical factors, and must be tailored to meet the specific needs of each commodity for several different geographical regions. Currently available chemical alternatives have varying degrees of potential negative environmental impacts, related to worker exposure, air and water quality, and long-term exposure of surrounding populations.

Potential negative impacts have already limited the use of some alternative chemicals through buffer zone requirements and township cap regulations. In addition, existing alternative chemicals control only a limited spectrum of pests and weeds.

New approaches are needed to supplement currently registered products, as well as provide alternative tools. New chemistries and new application technologies to optimize efficacy of new and currently available chemicals need to be evaluated under field conditions and over multiple cropping cycles. In addition, non-chemical management strategies need to be developed and evaluated within the framework of existing commercial production systems. Integration of nematode- and pathogen-resistant plant germplasm into commercially acceptable crop varieties, for all sectors, as well as grafting desirable scions onto pest and pathogen resistant rootstocks, would increase the potential for pest and pathogen management. Development of new biological control agents and improvements in the efficacy and applicability of existing biological agents are needed. A greater understanding of the mechanisms of activity and the genetic basis of control will enhance the usefulness of biological control agents. Where economics allow, cultural practices, such as fallowing, can also be a useful component in an integrated management production system. Each of these tactics can be improved through the integration of multiple compatible approaches into long-term, sustainable systems. All new management strategies, whether single tactic or an integration of multiple strategies, need to be evaluated under commercial field conditions with significant pest and pathogen pressure, over multiple cropping cycles, to determine whether they constitute technically and economically feasible alternatives to methyl bromide.

Research Needs: Data regarding efficacy, spectrum of activity, and feasibility of use are needed for new chemicals. Research is needed to enhance the selection of desirable traits among existing biological control agents to improve consistency, efficacy, and commercial acceptability. New populations of biological agents should be investigated and screened for their suitability for use in integrated systems, either as individual isolates or as beneficial populations arising from whole-farm management practices. Additional research on germplasm development and selection can better address hard-to-control pests. Cultural management tools, such as cover crops, soil amendments, crop rotations, and alternative mulches, should be evaluated for their potential contributions to multi-component alternative production systems. Characterizing the impact that these alternative approaches have on soil biological communities will allow for optimization of systems. A more thorough understanding of how system components work will allow for more effective coupling of pest control measures. Knowledge of each alternative system’s efficacy against target pests, ease of implementation, and required modifications to existing practices is needed. Ultimately, the impact of alternative systems on crop yield and profitability must be compared to methyl bromide and be acceptable to the producer. In the case of systems that include crop rotations or double-cropping, this information must be gathered for all crops included in the production plan. On-farm research trials that involve the cooperation of researchers, growers, farm managers, contract fumigators, and county extension agents and specialists are critical for determining the applicability of alternative production systems to individual users of methyl bromide.

Anticipated Products:
- New chemicals controlling targeted pests.
- Other commercially viable biological control agents.
- New germplasm lines with improved resistance to pests and acceptable horticultural characteristics.
- Multi-component management systems that address current and emerging pest problems, to keep productions systems viable and avoid the potential for future dependence on any single chemical pesticide.
- A knowledge base containing performance measures for various target pests and cropping system conditions, comparing newly developed approaches or integrated systems with methyl bromide soil fumigation.

PROBLEM STATEMENT 1A: ACCOMPLISHMENT SUMMARY

Since methyl bromide was banned in 2005, ARS has continued to evaluate a spectrum of alternatives. This section summarizes the overall achievements in the past 5 years this problem statement, with a focus on scientific impact and potential benefits. Selected accomplishments follow this summary.

The overarching goal of research conducted as part of this problem statement is to develop new technologies that can be integrated into production systems for management of plant pathogens, nematodes, and weeds. New chemicals (such as iodomethane) and new uses for available chemicals (drip-applied 1,3-D) were tested for efficacy and phytotoxicity in annual and perennial production systems. Data from these tests contributed to labeling products for use as methyl bromide alternatives. Development of biological control agents ranged from initial discovery to understanding mechanisms of control and survival. Biocontrol was also integrated into production systems that have been adopted by growers. The feasibility of grafting scions with desirable horticultural characteristics onto nematode-resistant rootstock for tomato, muskmelon, and watermelon was demonstrated in the field. ARS researchers discovered walnut germplasm resistant to crown gall, as well as identified pepper germplasm with resistance to crown rot, and a transgenic plum rootstock with resistance to ring nematode for potential use as rootstock for peach. ARS researchers also developed a system for using solarization plus fallow tillage for the management of yellow nutsedge and a method for using brassicaceous seedmeal amendments plus resistant rootstock to manage apple replant disease caused by a complex of lesion nematode and *Pythium* species Anaerobic soil disinfestation, using water and molasses plus broiler litter, was optimized for management of weeds, nematodes, and *Phytophthora capsici* (which causes blight of solanaceous and cucurbit crops). Seedmeal of *Brassica juncea* was found to be nematotoxic and the least phytotoxic to pepper seedlings of the seedmeals tested. This research has provided new tools for pest and disease management, and provided data to inform management decisions.

PROBLEM STATEMENT 1A: SELECTED ACCOMPLISHMENTS

Anticipated Product 1A-1: *New chemicals controlling targeted pests.*

Reduced rate fumigant alternatives to methyl bromide for Pacific Northwest forest nurseries. The $350 million Pacific Northwest forest nursery industry has experienced tree seedling losses in excess of 50 percent in non-fumigated fields due to the presence of soilborne diseases. ARS researchers evaluated reduced rate alternative fumigant treatments for methyl bromide for their ability to control soilborne diseases in forest nurseries and found four formulations that were as effective as methyl bromide in reducing disease damage. These results allow growers to continue to manage soilborne diseases as methyl bromide use is phased out; the ability to use reduced rates will decrease chemical inputs and result in lower fumigant emissions.

Methyl bromide alternatives for grape replant. In an 8-year grape replant trial, ARS scientists found that 1,3-dichloropropene (1,3-D) plus chloropicrin, iodomethane (also known as methyl iodide) plus chloropicrin, and propargyl bromide generally controlled rootknot and citrus nematodes similarly to methyl bromide. Rootstock selection had a profound effect on nematode populations; the rootknot resistant rootstock "Freedom" kept nematode numbers low, regardless of preplant fumigation treatment. Where this particular nematode is the major replant problem, use of a resistant rootstock may reduce the need for preplant fumigation.

Methyl bromide alternatives for gladiolus production demonstrated. In field trials to test methyl bromide alternative chemicals in gladiolus production, ARS scientist found that all chemical treatments reduced populations of the pathogen *Fusarium oxysporum*, in both the drip and shank injected trials compared to the untreated controls, except for Telone C35®, which did not perform well for control of the pathogen in the shank trial. Bulb yield from the alternative treatments was generally comparable to the standard methyl bromide:chloropicrin treatment, and the trend was toward increased yield in shank treatments than drip treatments. These results suggest that gladiolus bulb crops can be successfully grown with these alternative treatments.

Effect of dimethyl disulfide on soil pathogens and nematodes. Laboratory experiments conducted by ARS scientists with dimethyl disulfide, a potential methyl bromide alternative for preplant soil fumigation, showed that nematode control was good, but fungal and weed control was poor at all dimethyl disulfide concentrations. In Florida field trials, ARS scientists found good weed control, although it was not as good as methyl bromide when repeated for 3 years. In these field trials, pathogen control, particularly of *Pythium* diseases on ornamentals, was very good with dimethyl disulfide. This research indicates that dimethyl disulfide can be a potential methyl bromide alternative for nematode control, but more research is needed to determine where it can be successfully used.

Methyl bromide alternatives for the Florida floriculture industry. This cooperative research project, with university scientists, yielded new information on the use of soil solarization and fumigants, including iodomethane, as well as the use of reduced rates and alternative formulations of methyl bromide applied under metalized films for weed, nematode, and pathogen control in cut flowers in Florida. Four seasons of data on snapdragon (*Antirrhinum majus*) and celosia (*Celosia argentea*) were collected from commercial production fields. Pest pressure varied according to location and ranged from high nematode and weed pressure to low nematode pressure but high weed pressure. Results of studies showed that iodomethane applied under metalized film provided weed control comparable to high rates of methyl bromide (98:2 400 pound/acre) under high density polyethylene film, and lower rates of methyl bromide (98:2 200 pound/acre) under metalized film. Low rates of methyl bromide (67:33 methyl bromide:chloropicrin 200 pound/acre) under metalized film did not provide good weed control. Soil solarization provided better control of white clover (*Trifolium repens*) than any fumigant tested. Under high nematode pressure, iodomethane was as effective as methyl bromide in controlling rootknot nematodes in soil, although populations rebounded late in the growing season with both fumigants. Nematode populations rebounded at harvest, but early season nematode control was sufficient to result in yield maintenance. In additional field trials with cut-flower and caladium growers using multiple plastic tarp types and the alternative fumigants iodomethane:chloropicrin and dimethyl disulfide, ARS researchers identified significant statistical interactions between cultivar selection, principally based on rootknot nematode susceptibility and fumigant selection. Repeated application of dimethyl disulfide resulted in a gradual increase in weed pressure. These crops have been included on the federal labels for the alternative fumigants.

Management of nutsedge in vegetable crop production. Nutsedges significantly limit vegetable crop production, and reproduce primarily by underground tubers. Therefore, effective management systems need to reduce tuber production. Halosulfuron is an herbicide that reduces nutsedge populations in vegetable crops; however crop tolerance level limits adoption of this methyl bromide alternative. ARS researchers found that cucumber was tolerant of soil and topical applications of halosulfuron, while squash sensitivity to halosulfuron was too variable for commercial use. Data on cucurbit tolerance to halosulfuron were used to support registration of halosulfuron for cucumber through the IR-4 Minor-Use Crops Program. Squash tolerance to halosulfuron was variable, so registration for squash was not pursued. In additional research, ARS scientists determined that glyphosate was effective in halting nutsedge tuber production and reduced existing nutsedge tuber biomass by 50 percent at standard use rates. Purple nutsedge tuber biomass and foliar growth responded similarly to glyphosate. In contrast, yellow nutsedge tuber biomass was reduced at lower application rates of glyphosate than was foliar growth. Glyphosate can be used, in conjunction with preplant alternatives, to minimize tuber production of nutsedge between spring and autumn vegetable crops.

Herbicide crop safety in perennial woody nurseries. Weed control is an important concern for production of woody nursery crops in California but phytotoxicity information is often not available for existing and new herbicides. ARS scientists conducted 2-year field trials and found that the herbicides pendimethalin, thiazopyr, and dithiopyr can be safely used in the nurseries. However, the herbicide oxyfluorfen was differentially phytotoxic to some nut tree rootstocks in the nursery. Also, a series of sulfonylurea herbicides were phytotoxic in tree nurseries. The herbicide foramsulfuron was not phytotoxic to a peach rootstock. The results of these herbicide evaluations contribute to the selection and adoption of new weed control strategies in perennial nurseries. In separate studies, field trials were carried out by ARS scientists on unlabeled herbicides. Dithiopyr provided weed control in perennial crop field nurseries equal to or better than oryzalin, with similar crop safety. Pre-emergence rimsulfuron and flumioxazin were less phytotoxic on prunus rootstock, planted as hardwood cuttings, compared to seeded rootstock cultivars.

Nematicidal extracts from the plant genus Plantago (Plantain). Plant extracts are one potential source of nematode management tools urgently needed by growers. ARS researchers evaluated the extracts from roots and shoots of two plantain species, *Plantago lanceolata* and *Plantago rugelii*, for toxicity to the rootknot nematode *Meloidogyne incognita*; the beneficial bacteria *Enterobacter cloaca*e and *Pseudomonas fluorescens*; the beneficial fungus *Trichoderma virens*; and the plant-pathogenic fungi *Phytophthora capsici, Pythium ultimum, Fusarium oxysporum* f. sp. *gladioli*, and *Rhizoctonia solani*. In water and in methanol, all of the root and shoot extracts were toxic to eggs and second-stage juveniles of rootknot nematode. At the lower concentrations, second-stage juveniles were more sensitive than eggs to the toxic compounds, but both life stages were equally affected at higher concentrations. None of the extracts were toxic to the bacteria or fungi under the test conditions. This research identified common plant species as sources of natural nematicidal products for possible utilization by growers.

Anticipated Product 1A-2: *Additional commercially viable biological control agents.*

Improving the production of the biocontrol agent (Dactylaria higginsii) for the control of nutsedge. Multiple laboratory, greenhouse, and field trials have been conducted to evaluate the use of the biocontrol agent, *Dactylaria higginsii*, in combination with multiple types of hay for solid substrate production of inoculum to control troublesome nutsedge weeds. For mass production of *D. higginsii*, 14 solid substrates in the form of dried, cut shoots of various plants were tested. Spore yields were highest when the fungus was grown on purple nutsedge hay without amendments for 4 weeks. Spores produced on sorghum and cogongrass hays were slightly larger and thicker walled than those produced on other hay. Spores produced on sorghum were the most virulent on nutsedge seedlings. *D. higginsii*-infested cogongrass hay was most effective in the suppression of nutsedge, possibly because cogongrass also has some allelopathic properties in addition to the biocontrol agent.

Nutsedge management using mulch and the fungal biological control agent, Dactylaria higginsii. Four seasons of field trials were conducted on a research farm and a commercial vegetable production farm using hay mulches that were combined with either *Dactylaria higginsii* or *Trichoderma* sp. These field trials have confirmed that mulches of cogongrass infested with *D. higginsii* or *Trichoderma* sp., non-infested cogongrass, and bahiagrass hays were most effective in suppressing the growth of nutsedge. The trials on the farm also included the treatment combination of biodegradable paper mulch and plastic mulch. The combination of paper and plastic mulch resulted in the greatest reduction in the nutsedge population during the tomato cropping season. The combination of paper and plastic mulch has been adopted by a large commercial organic strawberry producer in California.

Cyclic lipopeptides produced by biocontrol strains of Pseudomonas fluorescens confer resistance to protozoan grazing. Integrated strategies are needed to suppress apple replant disease in orchards. ARS scientists showed that certain beneficial bacteria, which are useful in the management of apple replant disease, produce cyclic lipopeptides that inhibit plant pathogenic fungi and provide biological control of replant disease. Rhizobacteria have been shown to control apple replant disease through production of cyclic lipopeptide surfactants, such as massetolide, which is produced by strain SS101. In studies that employed SS101 and its surfactant deficient mutant strain 10.24, ARS scientists demonstrated that both strains control *Pythium* species irrespective of surfactant production. These data demonstrate that surfactant production is one of multiple mechanisms employed by SS101 in the suppression of *Pythium* species; and that this strain has significant potential for use in conjunction with seedmeal amendments, which tend to elevate such populations, in an integrated strategy for control of apple replant disease.

Potential remediation of soil infested by Phytophthora ramorum, with Trichoderma species. Novel methods to control the sudden oak death pathogen, *Phytophthora ramorum,* in nursery production areas are badly needed to prevent serious losses suffered by growers in pathogen infested areas. ARS scientists examined 16 *Trichoderma* isolates for their potential to parasitize *P. ramorum* propagules in soil. Preliminary tests in the field identified one isolate that when added to soil plots significantly reduced *P. ramorum* soil populations after 2 weeks compared to non-treated plots. This research demonstrates that biological control has the potential to be effective in remediating *P. ramorum* infested soil and that the control agent has the potential to be developed into a commercial product.

Metabolic activity of plant-beneficial bacteria significantly impacted by nutrient inputs from plants. Using a mutant of the plant-beneficial bacterium *Enterobacter cloacae,* ARS scientists showed that the metabolic stress response pathway called RpoE is critical for biological control of soilborne pathogens, colonization of plant roots, and growth on complex mixtures of nutrients found in exudates from roots. This is the first time that the RpoE stress response pathway was demonstrated to be important in growth on root exudates and that complex mixtures of nutrients in root exudates were shown to cause bacterial stress. ARS scientists developed methods to determine the impact of seeds with dramatically different nutrient release rates on metabolic activity of the plant-beneficial bacterium *Enterobacter cloacae*. This demonstrated that seeds and nutrient inputs from seeds dramatically influence overall metabolic activity of plant-beneficial bacteria in soil, which is being developed as a metric of performance by plant-beneficial bacteria. This information is useful to enhance performance of biological control bacteria for suppression of soilborne plant diseases.

***Development of a collection of Trichoderma isolates with disease suppression capabilities against Phytophthora capsici on bell pepper*.** Control measures are needed for pepper blight caused by the soilborne pathogen *Phytophthora capsici*. ARS scientists discovered five genetically distinct isolates of *Trichoderma* that significantly reduced blight incidence on bell pepper in greenhouse pot assays. These isolates are being used by scientists in studies where combinations containing these isolates are analyzed for suppression of *Phytophthora* blight on pepper in a number of different soil environments.

Assessing impact of soil microbial populations and activity following the use of plant-growth-promoting rhizobacteria-based inoculants on nematode suppression. ARS scientists, in collaboration with university researchers, developed methods for measuring soil microbial activity and population size in relation to the application of beneficial microbial soil inoculants. Two commercial rhizobacterial biological inoculants, BioYield and FZB42, induced significant reductions in nematode eggs per gram of root, juvenile nematodes in soil, and galls per plant. Additionally, increases in total culturable bacteria and heat-tolerant bacteria in the tomato rhizosphere were detected in plants treated with the two inoculants. Despite changes in populations, no increases in microbial activity was detected, indicating that nematode suppression can result from plant-growth-promoting rhizobacteria-based inoculants, and that these outcomes are related to bacterial density, but not to soil microbial activity in the rhizosphere.

A new bacterial (Bacillus subtilis) biocontrol agent is characterized. ARS scientists identified and molecularly and biochemically characterized a new potential biocontrol agent, *Bacillus subtilis* (ME488). Strain ME488 suppressed the diseases caused by *Fusarium oxysporum* f. sp. *cucumerinum* on cucumber and *Phytophthora capsici* on pepper in pot assays. Strain ME488 is being further investigated for use in managing soilborne diseases of vegetable crops and ornamental plants.

Replant disease control in organic orchard systems. Effective non-fumigant and non-chemical strategies for controlling apple replant disease have long been desired within the tree fruit producer community. ARS researchers examined preplant application of brassicaceous seedmeal formulations, used in conjunction with a virtually impermeable film, for management of replant disease in field trials at three commercial/research organic orchard locations. Seedmeal formulations provided levels of disease control and tree growth response that were equivalent or superior to that obtained with preplant 1,3-D:chloropicrin soil fumigation. Across orchard systems, suppression of root infestation by lesion nematode and *Pythium* species as a result of seedmeal amendment was numerically superior to preplant soil fumigation. The most effective seedmeal formulation for replant disease control was apple rootstock dependent. Results indicate that autumn or spring applications will be effective in higher organic matter loam soils. However, in light textured sandy soils, extended plant-back periods will be required and only applications made in the autumn prior to planting will be possible due to potential phytotoxicity issues. This research indicates that there is an attainable prescription based, biologically viable alternative to preplant soil fumigation for the management of apple replant disease in organic and conventional production systems.

Anticipated Product 1A-3: *New germplasm lines with improved resistance to pests and acceptable horticultural characteristics.*

Resistance to Pythium root rot in pepper. *Pythium* root and crown rot of pepper significantly reduces bell pepper yields in the southeastern United States. ARS scientists in cooperation with university scientists identified resistance to *Pythium* root and crown rot in wild pepper germplasm. Discovery of resistance will be useful in the development of bell pepper varieties with resistance to *Pythium* root and crown rot.

Adaption of vegetable grafting technologies for fresh vegetable production in the United States. ARS scientists, in collaboration with university scientists, improved techniques for increasing the survival rate of grafted pepper plants. Following greenhouse studies with grafted tomatoes and grafted peppers planted in non-fumigated soil to identify resistant rootstock, field tests were established in Florida. The use of grafting for rootknot nematode control in tomato, muskmelon, and watermelon was compared to fumigation, over four growing seasons, in a field infested with rootknot nematodes (*Meloidogyne* species). Rootstock/scion combinations were evaluated for 2 years in untreated soil and soil fumigated with methyl bromide, iodomethane, or dimethyl disulfide. Three rootstocks, each with some reported resistance to nematodes, were grafted to the hybrid cultivar FL-47 as the scion and compared to FL-47 on its own roots. Treatments were evaluated for plant growth, disease incidence, nematode resistance, yield, and fruit quality. Two years of additional microplot experiments were conducted concurrently, with tomato and melon field trials, using the same grafted tomato and melon transplants, and were inoculated with nematodes to insure data availability of the host status of rootstocks for *M. incognita*. Results show that galling and soil populations of rootknot nematodes on tomato, muskmelon, and watermelon can be reduced with resistant rootstocks. Both dimethyl disulfide and iodomethane provided nematode and weed control that was similar to methyl bromide in field plots. A key discovery was that the use of grafting with herbicides alone did not result in pest control and yields that were equivalent to methyl bromide. Grafting combined with alternative fumigants can provide acceptable nematode control for tomato and melon crops.

Nematode resistance in watermelon. In field tests in South Carolina and Florida, ARS scientists identified wild watermelon (*Citrullus lanatus* var. *citroides*) lines resistant to rootknot that performed well as rootstocks, and produced high yields for the grafted watermelon plants. These wild watermelon rootstocks could be a useful alternative to soil fumigation for managing rootknot in watermelon fields, and can be used by seed companies interested in developing rootstock varieties for grafted watermelon.

The impact of ring nematode on grapevines grafted to different rootstocks. The ring nematode, *Mesocriconema xenoplax*, is a common economically important root pest of grapevines worldwide. In a 4-year study, ARS researchers discovered that this nematode initially decreased root growth, but above-ground impact on plant productivity was not apparent until the third year. In addition, the apparent ring nematode resistance of two rootstocks, 101-14 and 420A, broke down in the third year, and only one rootstock - 420A - remained highly resistant to the nematode. These results will guide growers in rootstock selection and direct the timing of management practices to minimize the impact of ring nematode on vine establishment and productivity.

Solarization for suppression of ring nematode. The ring nematode, *Mesocriconema xenoplax*, is the only nematode associated with predisposing trees to peach tree short life disorder and bacterial spot in the southeastern United States. ARS researchers investigated the control of a ring nematode population using a mixture of biocontrol bacteria combined with soil solarization or wheat from 2004-2010. Inter-planting the wheat each fall served as an overwintering host for the biocontrol bacteria while the peach trees were dormant during the winter months. Results indicate that the biocontrol cocktail did not suppress the ring populations, but soil solarization combined with wheat inter-planting was as effective as methyl bromide fumigation in increasing tree survival from peach tree short life disorder for at least 5 years after orchard establishment. These data provide useful insights into the potential use of soil solarization as a preplant alternative to chemical control of the ring nematode on sites with peach tree short life disorder in the southeast.

Host status of transgenic plum lines to the ring nematode, Mesocriconema xenoplax. Ring nematode, *Mesocriconema xenoplax*, is associated with making peaches more susceptible to peach tree short life disorder. Evaluating transgenic plum rootstocks for resistance to ring nematode is important in determining the potential use of these rootstocks as a management tool for the peach industry in the southeastern United States. Three plum lines were tested and results indicated that all three lines supported ring nematode reproduction, but one line - 5D - suppressed nematode populations more than the other two. These results provide information on the potential of genetically transformed plum rootstock as a management tool for ring nematode in peach in the southeastern United States.

Host status of peach rootstocks to a new rootknot nematode. In 2001, a new rootknot nematode, *Meloidogyne mayaguensis*, was detected in Florida. Evaluating rootstocks for resistance to *M. mayaguensis* is important in determining the economic impact this nematode may have on the peach industry, especially in light of the increased interest of growing peaches in Florida. Results of tests performed on the rootstocks Nemaguard and Flordaguard by ARS scientists indicated that both rootstocks were poor hosts to *M. mayaguensis*, with Flordaguard being immune.

Disease resistant walnut germplasm. Crown gall is an important disease in walnut and resistant germplasm could save $20 million in annual losses. ARS scientists found, under greenhouse conditions, durable crown gall resistance in the species *Juglans microcarpa, J. ailantifolia, J. mandischurica,* and the *Pterocarya* accessions. Over 1,500 individual, greenhouse propagated, *Juglans* seedlings were screened for crown gall resistance. Approximately 15 percent of the rooted dormant cuttings from mother trees exhibiting crown gall resistance, continued to exhibit crown gall resistance. New directed crosses were made, generating inter-specific hybrids between male and female trees, which exhibited various degrees of crown gall resistance.

Anticipated Product 1A-4: *Multi-component management systems that address current and emerging pest problems, to keep productions systems viable and avoid the potential for future dependence on any single chemical pesticide.*

Controlling soil pathogens with steam. Steam is a possible non-chemical methyl bromide alternative for killing soilborne pathogens. California field trials were carried out by ARS scientists who applied steam via drain tile or spike hose to control soilborne plant pathogens. Immediately after steam treatment using the spike hose, populations of *Fusarium oxysporum* and *Pythium* species were not significantly different in the treated soil, than in the untreated control soil. At 4 months after steam treatment with the drain pipe, *Fusarium* populations were significantly lower in one of four trials than the untreated control. This research indicates that steam had mixed success in controlling these soil pathogens in this field situation, which differs from results with steam in Florida fields reported below.

Combining soil solarization and steam for soilborne pest control. Treatments on a commercial flower production farm in Florida included solarization followed by a steam treatment using standard 3-inch perforated plastic drain pipe (S1), and solarization followed by a steam treatment using custom-drilled plastic drain tile with 1/16-inch holes spaced every 1.5 inches (S2). Steam application followed the 4-week solarization period in mid-October. Plots were steamed for sufficient time to reach the target temperature of 158°F for 20 minutes. Prior to steam treatments, rootknot nematode populations were relatively low; steam treatments resulted in rootknot nematode populations that were equivalent to methyl bromide and lower than solarization alone. At the end of the season, rootknot nematodes in larkspur roots in the S2 treatments were reduced to the same level as with methyl bromide. Galling on larkspur was lower in both steam treatments than in the methyl bromide treatment. Steam treatments killed all nutsedge that had emerged under the plastic, but due to high variability, differences between treatments were not statistically significant. Soon after treatment application, solarization plots had significantly more goosegrass and spurge survivors than steam or methyl bromide treatments. In snapdragon, *Carolina geranium* was a dominant weed and was best controlled by the methyl bromide treatment and the S2 treatment. In delphinium species, white clover was best controlled by the S2 treatment, which was significantly lower than in solarization plots. Total weight of weeds collected from the delphinium subplots was significantly lower in the methyl bromide and steam plots than in those treated with solarization alone. Approximately 1.23 gal of propane were used to effectively treat one cubic yard of soil.

Management of nematodes and other soilborne pests in floriculture production systems. ARS researchers, in cooperation with the university colleagues, determined that snapdragon and nasturtium were susceptible to and supported high populations of the nematodes *Meloidogyne incognita* (race 2) and *M. javanica*, while the marigold, zinnia, salvia, and carnation cultivars were poor hosts. Delphinium showed light galling with some intermediate nematode population levels, but was significantly less susceptible than snapdragon, and often similar to the resistant flower species. Data on the use of soil solarization for nematode control in floriculture crops indicated that eggs and juveniles of

Meloidogyne incognita can be killed over time at temperatures of 40-42°C. These temperatures are substantially lower than those temperatures of greater than 45°C typically expected under solarization. However, lethal effects at reduced temperatures required exposure to those temperatures for more than 13 hours up to several days, so the recommendation to keep solarization films in place for 6 weeks remains unchanged.

An integrated system of solarization and fallow tillage to control yellow nutsedge in the absence of methyl bromide fumigation. Yellow nutsedge is difficult to control in small, restricted areas (such as home gardens or crop seedbeds for transplant production) and in organic cropping systems. Previously, solarization was reported to be inconsistent in controlling perennial nutsedge, particularly in temperate regions. ARS researchers developed an integrated system of soil solarization and fallow tillage during the summer that abates yellow nutsedge and nematodes, with benefits of this system seen for several growing seasons. Solarization can be an effective weed control alternative in temperate regions, provided that the site is solarized for at least 90 days during the summer months. When combined with fallow tillage, summer solarization is a versatile, effective weed control system where fumigants and herbicides cannot be used.

Cultural weed control to manage perennial nutsedge in the absence of methyl bromide fumigation. Cultural weed controls are the foundation of an integrated weed management system. ARS researchers determined that applying a thin-film mulch immediately prior to transplanting cucurbit crops suppresses yellow nutsedge and allows rapidly growing transplants to shade these weeds without fumigants. The discovery of these cultural controls improves efficiency with less dependence on fumigants or herbicides. In cropping systems where this strategy could be implemented, savings would be approximately $500/acre.

Purple nutsedge thrives in black polyethylene mulch systems. Nutsedges are among the most troublesome weeds in fresh market vegetable crops of the southern United States. ARS researchers determined the appropriate use of polyethylene mulch was a significant factor in managing nutsedge. Black mulch increased purple nutsedge shoot production 85 percent and patch size 91 percent relative to non-mulched treatments. Yellow nutsedge growth was suppressed by black mulch, producing one-third fewer shoots and forming patches that were half the size of the non-mulched control. This research provides an explanation for the greater presence of purple nutsedge in mulched vegetable systems, indicating a potential shift in species composition from yellow nutsedge, the more common species in the region, to purple nutsedge.

Anticipated Product 1A-5: *Knowledge base containing performance measures for various target pests and cropping system conditions comparing newly developed approaches or integrated systems with methyl bromide soil fumigation*

Anaerobic soil disinfestation as an alternative to methyl bromide fumigation. ARS scientists, in cooperation with university colleagues, further developed a technique using a combination of composted broiler litter and a carbon source, with soil saturation and heating, to create an anaerobic condition that fosters weed, nematode, and soilborne plant pathogen control. When soil was amended with both litter and molasses, the effect on anaerobicity was stronger than that of either broiler litter or molasses individually. Using a previously formed false bed (single pass of bed former), this approach was successful. In plots receiving the combination, control of yellow nutsedge emerging though the plastic early in the season was equivalent to control provided by methyl bromide treatment. At pepper harvest, there were few significant differences between anaerobic soil disinfestations treatments and the untreated check, with regard to nutsedge emerging through the plastic. However, total weed biomass harvested from transplant holes at pepper harvest indicated that weeds in treatments including amendment with either molasses or broiler litter, regardless of applied irrigation, were controlled as well as with methyl bromide treatment. Weed control with solarization alone was also better than the untreated check, though not equivalent to treatment with methyl bromide. Control of *Phytophthora capsici*, introduced in buried inoculum in nylon mesh bags, was equal to that of treatment with methyl bromide for all treatments except the untreated check. There was an indication of increased numbers of non-pathogenic, beneficial nematodes in some treatments. The weed control observed during the bell pepper trial was maintained during the eggplant double crop.

Efficacy of brassicaceous seedmeal amendments for replant disease suppression is dependent on rootstock. Studies were conducted to assess the interaction between apple rootstock and the capacity of brassicaceous seedmeals to provide control of two components of the pathogen complex that incites replant disease: *Pratylenchus penetrans* and *Pythium* species. ARS scientists discovered that Geneva series rootstocks were less susceptible to root infection by native populations of *Pythium* species and supported lower populations of *P. penetrans* than did rootstocks of the Malling or Malling-Merton series. Significant interaction between rootstock and seedmeal was detected and nematode suppression in response to *Brassica napus* or *Sinapis alba* seedmeal was only observed when used in concert with a tolerant rootstock; while *B. juncea* seedmeal suppressed lesion nematode root populations irrespective of rootstock. These findings demonstrate that utilization of brassicaceous seedmeal amendments for replant disease suppression must employ an appropriate rootstock to achieve optimal disease control.

Mustard seedmeal amendments for suppression of rootknot nematodes. Mustard seedmeals are waste by-products of the biodiesel industry, resulting from the extraction of oil from seeds. Methods are being developed to utilize these seedmeals in agricultural applications, thereby eliminating waste disposal issues and augmenting profits, while enhancing agricultural practices. These seedmeals contain naturally occurring chemicals that make them of interest as management agents for weeds and soilborne pathogens. Previous studies indicated that seedmeals from two species of mustard, *Brassica juncea* and *Sinapis alba*, are nematotoxic. ARS scientists determined that treatment with seedmeal from *B. juncea* tended to be the least toxic to pepper seedlings, indicating that nematotoxic rates of *B. juncea* could be applied relatively close to the time of pepper transplant. Germinating lettuce seeds were not as sensitive as pepper seedlings to *S. alba* seedmeal. This research is valuable to scientists optimizing the use of seedmeal amendments for managing plant-parasitic nematodes without toxicity to crop plants. In additional studies, *B. juncea* and *S. alba* were applied to soil individually at equal rates, and as 1:1 and 1:3 combinations. Longer pepper shoots, greater plant weights, and lower nematode galling indices tended to result from an application of *B. juncea* seedmeal and one of the seedmeal combinations. These treatments also tended to result in low numbers of nematode eggs per root weight. This demonstrated that a combination of seedmeals could be as effective against nematodes as an individual seedmeal, potentially allowing for greater weed suppression, along with reductions in nematode populations.

Groundcover suppresses rootknot and root lesion nematode populations. A non-chemical alternative to preplant chemical control of nematode pests for peach growers is needed. ARS scientists evaluated tall fescue grass cultivars for susceptibility to the southern, peanut, northern, and Javanese rootknot nematodes, ring nematode, and root lesion nematode. Results indicate tall fescue cultivars were either poor or non-hosts for most rootknot and root lesion nematodes indicating a potential role for tall fescue grass as an alternative to preplant chemical control of certain rootknot and root lesion nematodes under field conditions.

Crop rotation for management of Verticillium wilt of strawberry. Strawberry is highly susceptible to *Verticillium* wilt. ARS scientists, in collaboration with university researchers, demonstrated that crop rotation with broccoli (which is not susceptible to *V. dahliae*) can reduce populations of the pathogen in the soil and thereby reduce the impact of disease on yield. While not sufficient as a stand-alone replacement for methyl bromide, broccoli rotations can be part of an overall management scheme for keeping pathogen populations at low levels. With the current economic model used by conventional growers this approach is not always economically feasible, but it is being used by some organic strawberry producers and is an option for conventional growers if the economic model changes.

PROBLEM STATEMENT 1B: PEST MANAGEMENT SYSTEMS TO OPTIMIZE EFFICACY OF PESTICIDES AND REDUCE HARMFUL EMISSIONS.

Problem Statement: Currently registered, chemically based alternative pest management systems, face existing and potential problems associated with township use limitations, emission control, and buffer zone restrictions. In addition, although a substantial amount of work has been done with many of the alternative fumigants, the lack of consistent performance across crops, pests, regions, soil types, and soil water content, reduces the likelihood of their adoption. Factors impacting the efficacy of alternative fumigants are poorly characterized. New materials used as alternative fumigants, which are nearing registration, have not been adequately tested in all crops and regions or over multiple cropping cycles.

Research Needs: Knowledge on emission characteristics and efforts to control emissions through fumigant application technology needs to be expanded. Performance of alternative fumigants needs to be evaluated in two ways: under controlled laboratory or small plot conditions where relationships among fumigant concentration, exposure time, environmental conditions, pest species, and growth stage need to be determined; and in the field, where factors such as chemical distribution, pest population density and distribution, pest interactions, and environmental and soil conditions influence efficacy.

Anticipated Products:

- Improved understanding of the impact of fumigant concentration, movement through soil, pest exposure time, soil temperature, soil moisture, soil type, and pest species on fumigant efficacy.
- Improved fumigant application methods that reduce emissions and enhance efficacy with less potential for negative environmental impacts.

PROBLEM STATEMENT 1B: ACCOMPLISHMENT SUMMARY

To ensure the widespread acceptance and use of technologies to replace methyl bromide as a soil fumigant, the goals for this problem statement were to identify and reduce the impact of critical variables that result in inconsistent efficacy of existing or developed alternative technologies for soil pest and pathogen control. Inconsistencies may result when alternatives are used in cropping systems with varying soil types and conditions.

Several advances were made over the last 5 years, resulting in the development or improvement of soil fumigant methodologies that combine various impermeable and/or metalized plastic film, bed preparation, and application technologies with reduced atmospheric emissions that meet the EPA Fumigant Re-registration Eligibility Decision. These advances benefit the fruit, vegetable, tree nut, cut-flower, and ornamental industries, which were previously dependent on methyl bromide for crop pest and pathogen control.

PROBLEM STATEMENT 1B: SELECTED ACCOMPLISHMENTS

Anticipated Product 1B-1: *Improved understanding of the impact of fumigant concentration, movement of fumigant through the soil, pest exposure time, soil temperature, soil moisture, soil type, and pest species on fumigant efficacy*.

Fumigant emissions affected by soil type and water content. Soil fumigation is used for different soil types and soil moisture conditions, however, the effects of soil texture and water content on atmospheric emissions are not well understood. ARS scientists determined that increasing water content up to field capacity reduced peak emission rate, delayed emission time, and reduced total emissions. This effect was more obvious in fine-textured than in coarse-textured soils. Linear correlation was found between emission and air-filled porosity in all types of soil. This finding will help growers and others who practice soil fumigation to develop effective agricultural practices towards reducing fumigant emissions.

Effect of organic amendment applied to surface soil without water treatment on fumigant emissions. Incorporation of organic materials to surface soil could be an effective strategy to reduce fumigant emissions. Data from field trials conducted by ARS scientists indicate that incorporation of composted manure at 5, 10, or 20 tons per acre did not significantly reduce emissions from soil fumigation. This research concluded that surface soil amendment with various rates of composted manure did not always result in emission reductions from field fumigation, although some laboratory results showed organic materials can effectively degrade soil fumigants and reduce emissions. Data generally supported that organic amendment or water applications may lead to reduced pest control efficacy.

Water seals to reduce fumigant emissions without reducing soil gaseous fumigant concentrations*.* Emission reduction from soil fumigation is required to improve air quality, while adequate fumigant concentrations are needed for pest control. In laboratory studies, ARS scientists demonstrated that water seals applied to soil columns following fumigant injection significantly reduced emissions for different textured soils without reducing fumigant concentrations in the soil profile. ARS scientists also demonstrated that increasing soil water content prior to fumigant injection significantly reduced emission peaks, which could minimize acute exposure risks to workers and bystanders. While these laboratory results need to be validated under field conditions, compared to plastic tarps, irrigation would be a low cost technique for reducing fumigant emissions. In field trials where proper water seals or pre-irrigation were applied, fumigant concentration or distribution in soil profile were not reduced compared to that under standard polyethylene tarp. However, weed data indicate that irrigation prior to fumigation tended to reduce weed control.

Anticipated Product 1B-2: *Improved fumigant application methods to reduce emissions and enhance efficacy with less potential for negative environmental impacts*.

Novel application strategy to limit fumigant emissions. Atmospheric emissions and potential bystander exposure risks are limiting grower adoption of alternative fumigants. ARS scientists designed a low disturbance soil fumigant applicator to reduce dose rates and mitigate atmospheric emissions in broadcast, shanked applications. The apparatus was shown to reduce atmospheric emission of soil applied chemical fumigants during demonstration trials by commercial forest seedling nurseries in Georgia and Alabama and a commercial sod producer in Fort Pierce, Florida.

Fumigant emissions using virtually impermeable films. The potential of using virtually impermeable film (VIF) to reduce emissions from field soil fumigation has been questioned because of potential damage to the film during field installation. Based on emission data collected from field trials conducted by ARS scientists, using VIF can reduce emissions to 1-3 percent of total applied fumigant as compared to emissions of greater than 60 percent without VIF. VIF improved weed control efficacy by retaining higher fumigant concentrations under the tarp than the commonly used polyethylene film. VIF is an effective means to reduce fumigant emissions and improve weed control efficacy, as long as VIF is successfully installed in the field.

Fumigant emissions using totally impermeable films. A new low permeable film, referred to as a totally impermeable film or TIF, effectively reduced fumigant emissions in laboratory tests. In large collaborative field trials, ARS, university, and State of California scientists demonstrated that TIF reduced peak emission rate up to 10 times lower than that from the standard polyethylene film. Over a 6-day period, the total emission loss with the TIF was reduced to below 2 percent of total fumigant applied; compared to a 30 percent emission loss with the polyethylene film. However, the emission surge upon cutting the TIF was much higher than with the polyethylene film, which indicated that a longer waiting time would be needed to reduce potential exposure risks. This new film can help improve buffer zone restrictions and enable many fields to be fumigated under the newly amended EPA regulations.

Fumigant emissions reduction technologies. ARS scientists conducted solid-tarp (broadcast) fumigant applications using various combinations of soil preparation techniques, application equipment, and covering tarps. Creation of a compaction layer on the soil surface prior to application and use of low disturbance fumigant application equipment with VIF significantly improved retention of soil fumigants in the soil thus lowering atmospheric emissions. Fumigant retention in soil was further improved by combining the various procedures and films. At 15 days after application, only the VIF film significantly improved fumigant retention in soil.

Tree site-specific spot fumigation to reduce total fumigant emissions. Reducing emissions of volatile organic compounds from fumigant pesticides is mandatory in California, especially in “nonattainment areas” such as the San Joaquin Valley which do not meet Federal air quality standards. In a 2-year field study, ARS scientists examined the feasibility of site-specific spot application of fumigants at future tree sites. Pest control efficacy was not evaluated directly but the fumigant concentration-time index was computed using the measured soil gas concentrations for the 1-meter soil profile for four lateral distances from the fumigated tree sites. The concentration-time values indicate that pest control is only effective at depths greater than 20 centimeters for some fungal pathogens at the 15 centimeter radius and for nematodes at the 51 centimeter radius distance from the fumigated tree sites. Spot fumigation may achieve a 10-fold reduction in atmospheric volatile organic compounds load from fumigant pesticides, but pest control in the upper 20 centimeters of soil must be confirmed.

PROBLEM STATEMENT 1C: IDENTIFICATION AND MITIGATION OF EMERGING PROBLEMS.

Problem Statement: As growers move away from the traditional methyl bromide:chloropicrin soil fumigation treatments, shifts in soil biological communities will occur, as well as changes in soil physical and chemical characteristics. These shifts have the potential to be either beneficial or detrimental. Pests and weeds not previously of concern are likely to emerge as problems. Systems that encourage more diverse microbial communities that are resilient to disturbance could lead to the suppression of some soilborne pests. The implications of shifts in pest populations and the emergence of new pest problems will need to be anticipated, identified, and evaluated quickly. The potential impact of existing and emerging pests and weeds on crop production will need to be quantified for all crops in production systems using rotations, cover crops, double crop strategies, pesticides with a narrower spectrum of activity than methyl bromide, and/or resistant germplasm.

Research Needs: The impact of alternative systems on beneficial and detrimental soilborne communities will need to be assessed. Increased knowledge of soil biology, particularly in suppressive systems, will be required. New methods for the identification of current and emerging pests need to be developed. The identification of emerging issues will rely on continued enhancement of our understanding of microbial taxonomic classifications as supported by research in National Program 303: Plant Diseases, and other related national programs. Pest population thresholds that impact crop production will need to be quantified. Rapid identification of emerging pest problems will allow for modifications in component pest management system development.

Anticipated Products:

- New diagnostic and detection tools.
- Timely identification of emerging pest problems.
- Quantification of pest impacts on crop production.

PROBLEM STATEMENT 1C: ACCOMPLISHMENT SUMMARY

The overarching goal of research conducted in this problem statement is to detect and identify emerging problems. As production systems change in response to the methyl bromide phaseout, new problems arise not only in the crops historically treated with methyl bromide, but also in successive crops which benefitted from the pathogen control in the primary crop. For example, lettuce, which is often planted after strawberry, is now suffering from problems such as *Verticillium* wilt. New methods to rapidly and accurately identify emerging problems in both primary and following crops are needed. Toward this goal, ARS scientists improved diagnostic techniques for *Verticillium* diseases and discovered molecular characteristics to separate species. Molecular methods were used to accurately identify 19 *Pythium* species in coniferous tree seedling nurseries. Species not previously known to cause disease were found causing mortality in tree seedlings. ARS scientists developed a Web site for sharing genetic information on *Phytophthora*, which facilitates research and development of diagnostic tools for distinguishing among members of this important pathogen group. Improved diagnostic methods were developed for the sudden oak death pathogen, *Phytophthora ramorum*, and this technology was transferred to agencies regulating the spread of this emerging disease.

PROBLEM STATEMENT 1C: SELECTED ACCOMPLISHMENTS

Anticipated Product 1C-1: *New diagnostic and detection tools*

Web site supports Phytophthora research. The genus *Phytophthora* has approximately 90 species and is responsible for a wide range of crop plant diseases. ARS researchers initiated a collaborative project with university researchers to enhance understanding of the genus, simplify identification, stimulate research, and develop a Web-based database for the genus. The database includes complete morphological descriptions, information on host range and geographical distribution, a comprehensive molecular phylogeny using seven nuclear genes (four mitochondrial genes will be added shortly), and a section on molecular detection and identification. The *Phytophthora* database will serve as a resource for researchers working on the genus as well as a repository of future relevant research progress and information.

Rapid disease assay of Verticillium on lettuce. Conventional greenhouse assays for examining the pathogenicity of the soilborne fungus *Verticillium dahliae* require a 100-day testing period. ARS researchers developed a growth chamber technique that enables a more rapid assessment of the pathogenicity of *V. dahliae* on lettuce. The technique takes advantage of an early flowering lettuce accession line that develops disease symptoms quickly and speeds analyses of the *V. dahliae* lettuce interaction to 42 days.

Gene sets in two fungal pathogens that enable infection of lettuce. ARS researchers, along with a team of international researchers, analyzed the genomes of two soilborne fungal plant pathogens, *Verticillium dahliae* and *V. albo-atrum*, that cause vascular wilt diseases on over 200 plant species worldwide. The research discovered gene sets that enable the two fungi to infect their host crops and permit their ecological adaptation. Identification of the genetic basis for pathogenicity or host range expansion may lead to alternative strategies for the control of *V. dahliae* and *V. albo-atrum* in high value crops such as lettuce.

Genetic analysis of an important soilborne pathogen of lettuce and other important crops. *Verticillium* wilt, incited by the soilborne fungus *Verticillium dahliae*, is a serious disease of lettuce and many other important crop species. Current techniques for identifying sub-populations, such as different pathogenic races, of the pathogen are slow, and as a result may adversely affect management and cropping decisions by farmers. ARS researchers sequenced parts of the mitochondrial DNA from diverse isolates of the pathogen. The mitochondrial technique is currently under evaluation using a much larger number of field isolates of the pathogen to evaluate the utility of mitochondrial haplotype analysis for population studies of this important pathogen.

Expressed sequence tags (EST) libraries and public release of the Verticillium dahliae and V. albo-atrum genomic sequences. *Verticillium dahliae* and *V. albo-atrum* cause disease worldwide and threaten the sustainability of lettuce production and other crops in the United States. To facilitate genome annotation for the study of these pathogens ARS scientists prepared three normalized expressed sequence tags (EST) libraries from the *V. dahliae* lettuce isolate VdLs.17 and shipped them to university collaborators, where approximately 37,000 sequence reads were obtained. Working collaboratively with several university laboratories and Agriculture and Agri-Food Canada, the assembled genomic sequences and annotation of *V. dahliae* and *V. albo-atrum* were approved by the project collaborators and publicly released in 2008. Preliminary analyses of the whole-genome comparison between the eight chromosomes of *V. dahliae* and DNA sequences of *V. albo-atrum* reveal the presence of four major regions of non-synteny and *V. dahliae*-specific genes in these regions. DNA sequences, tools, and knowledge developed in this project are providing insight into the genetic components important for virulence and host range, pathogen detection, and may reveal new control targets.

Improved diagnostics for the Sudden Oak Death pathogen, Phytophthora ramorum. Several molecular methods for identifying *Phytophthora ramorum* have not been rigorously compared and validated for accuracy. ARS researchers coordinated with university researchers to conduct a blind testing of 11 of the diagnostic methods using a library of 400 isolates and 60 field samples. The results have been provided to APHIS to help regulatory agencies making decisions on diagnostic markers to identify this important quarantine pathogen.

Mitochondrial haplotype determination for Phytophthora ramorum. *Phytophthora ramorum*, causal agent of Sudden Oak Death, is under strict quarantine restrictions to prevent movement around the country. The mitochondrial genomes for two isolates of *P. ramorum* were sequenced and used to identify variation that would be useful for identification of individual isolates, which, since the pathogen reproduces only by asexual means, will be useful for monitoring the spread of specific pathogen genotypes. A total of four differences in mitochondrial sequences were identified in a collection of 40 isolates representing the geographic range of pathogen recovery. Rather than relying on DNA sequence analysis for determining haplotypes, PCR (polymerase chain reaction) amplification primers were developed so melt curve analysis could be used to identify the differences in mitochondrial sequences; this process is quicker and less expensive. The results of this work will provide regulatory agencies and researchers with additional tools for identification of this important quarantine pathogen.

Identification of Rhizoctonia species. The traditional method of identifying *Rhizoctonia* species by hyphal anastomosis reactions is often unreliable and time consuming. With collaborators, ARS researchers tested various molecular approaches to pathogen identification and showed that *Rhizoctonia* ribosomal DNA-ITS sequencing and analyses gave reliable identification of the pathogen to anastomosis group levels. A genome fingerprinting method (UP-PCR) accurately grouped *Rhizoctonia* isolates to species and anastomosis group. In addition, ARS researchers identified molecular markers (also called sequence characterized amplified region or SCAR) from the UP-PCR products that accurately identified isolates of major pathogenic anastomosis groups 1-IB and AG 2-2IIIB and differentiated these isolates from those of other anastomosis groups. These molecular identification methods for *Rhizoctonia* will assist in selection of appropriate fungicides and will facilitate plant breeding for resistance to *Rhizoctonia*.

Anticipated Product 1C-2: *Timely identification of emerging pest problems*

International movement of the Verticillium wilt plant pathogen on spinach seed. *Verticillium* wilt is a relatively new and devastating disease of lettuce, and the pathogen can persist in the soil for many years. ARS researchers, in collaboration with university scientists, assessed the possibility that *Verticillium dahliae*, the soilborne fungus that incites *Verticillium* wilt disease of lettuce and a wide range of other crop species, can be transmitted over long distances on spinach seed. The results of this assessment indicate that there has likely been dissemination of the fungus on spinach seeds from domestic and foreign seed production areas to the major vegetable production area of the Central Coast of California.

Anticipated Product 1C-3: *Quantification of pest impacts on crop production*

Pythium species of Pacific Northwest forest nurseries. *Pythium* species are economically important soilborne pathogens that stunt or kill tree seedlings produced for reforestation; however, the identity of these species in forest nurseries has been largely ignored. ARS researchers surveyed field soils at three nurseries and discovered 19 *Pythium* species based on DNA sequence. ARS scientists tested 12 *Pythium* species for pathogenicity to Douglas fir and all caused at least 25 percent mortality. This research identifies *Pythium* species not previously associated with damage to conifer seedlings. Each nursery was associated with a different predominate species. The results are significant because the use of non-selective disease management practices, such as fumigation, are becoming increasingly restricted by state and federal regulations. Knowledge of pathogen identity is the first step required to developing more targeted and integrated pathogen control measures.

PROBLEM STATEMENT 1D: LACK OF COMMERCIAL SCALE DEMONSTRATIONS OF THE TECHNICAL AND ECONOMIC FEASIBILITY OF CURRENTLY AVAILABLE ALTERNATIVES.

Problem Statement: Over the past 10 years, extensive research conducted by ARS and other USDA agencies, land grant universities, and private industry produced several technically feasible methyl bromide alternatives for some crops. However, widespread industry adoption of these alternatives has not occurred for several reasons, including, but not limited to: variability in performance of the alternatives coupled with incomplete knowledge on sources of the variation and means to manage it; the need to combine many of the alternatives with supplementary herbicides or other inputs for acceptable efficacy; inadequate regionally coordinated efforts to transfer the alternative technologies expeditiously, and; regulatory restrictions, especially in California, that limit uses of the alternatives. Establishment by ARS of an Areawide Pest Management Project for methyl bromide alternatives that addresses specific constraints hindering adoption in the Pacific West and South Atlantic areas will address this problem.

Research Needs: Establishment of large-scale, replicated field trials containing paired comparisons of methyl bromide to currently available alternatives will provide commercial growers with the knowledge and experience to successfully use methyl bromide alternatives. Data are needed over a range of biological, environmental, chemical, physical, operational, and economic variables associated with implementation of methyl bromide alternatives. Key variables and their critical values responsible for consistent and effective pest control with methyl bromide alternatives are not known for all management strategies, especially combinations of strategies. New technologies need to be validated under commercial conditions to facilitate acceptance of methyl bromide alternatives. Regional technology transfer programs are needed to provide growers and the supporting agricultural industry with the information and experience necessary for the successful implementation of methyl bromide alternatives.

Anticipated Products:
- Commercial-scale economic information comparing the various alternatives to methyl bromide.
- New pest management systems that have been field validated under the range of biological and edaphic conditions that typify large geographic regions.
- Optimized pest management systems using methyl bromide alternatives.
- Technology transfer program to deliver concepts, assessments, and technologies needed for adoption of methyl bromide alternatives.
- A list of the sources of variability that affect the performance of methyl bromide alternatives.
- A knowledge base of the relationships between pest complexes and methyl bromide alternatives.
- Model for areawide management of soilborne pests that can be utilized beyond initially targeted locations and commodities.

PROBLEM STATEMENT 1D: ACCOMPLISHMENT SUMMARY

The research conducted under this problem statement facilitates the adoption of methyl bromide alternatives throughout the production regions that were previously dependent on methyl bromide for soil pest and pathogen control. Where needed, existing technologies were optimized for different cropping systems and/or geographical regions, and new technologies were developed and assessed over a range of biological and edaphic conditions representative of where these new fumigation methods were to be used.

Through a series of demonstration plots, field trials, and workshops conducted over the past 5 years, producers and extension personnel have been introduced to the most effective soil pest and pathogen control technologies available as alternatives to methyl bromide. Improvements in soil fumigation were achieved by combining multiple technologies, such as new mulching materials and application technologies that reduced costs and emissions.

PROBLEM STATEMENT 1D: SELECTED ACCOMPLISHMENTS

Anticipated Product 1D-1: *Commercial-scale economic information comparing the various alternatives to methyl bromide.*

> ***Development and demonstration of a GPS controlled shank injection system for spot fumigation in orchards.*** Previous research indicated that preplant spot fumigation using handheld probes at tree sites can prevent almond replant disease while using much less fumigant than conventional strip or broadcast fumigation with shank injection equipment. However, the probe treatments involved undesirable applicator risk and labor expense. ARS scientists, in collaboration with university colleagues, developed a GPS controlled shank injection system which safely and economically fumigates tree sites and will dramatically reduce amounts of fumigant required to prevent almond and peach replant disease, thereby saving fumigant material cost and reducing fumigant emissions.

Anticipated Product 1D-2: *New pest management systems that have been field validated under the range of biological and edaphic conditions that typify large geographic regions.*

> ***Soil solarization as a non-chemical alternative to methyl bromide fumigation***. Soil solarization was conducted on two commercial cut-flower farms in Florida during the 2009-2010 growing season. Solid tarp solarization was used to cover moistened soil for a 6-8 week period. Based upon grower assessment of performance, yield, and cut-flower quality, the acreage treated with soil solarization was expanded for the following growing season (2010-2011).
>
> ***New chemicals for weed, nematode, and pathogen control***. ARS researchers, in cooperation with university scientists, conducted multiple field trials to evaluate a novel, reduced-risk chemical for control of weeds, plant pathogenic fungi and bacteria, and plant parasitic nematodes. The chemical's broad-spectrum pest control activity at relatively low application rates was confirmed. Potential negative interactions with fertilizer applications were identified and remediated. A full patent has been filed and a licensee of the material has been identified.

Anticipated Product 1D-3: *Optimized pest management systems using methyl bromide alternatives.*

> ***Efficacy of alternative fumigants***. Data on the efficacy of alternative fumigants are needed for growers to be able to make informed pest management decisions after the phase out of methyl bromide. ARS scientists, in collaboration with university scientists, participated in larger scale field evaluations with alternative fumigants and determined the efficacy of the fumigants in controlling soilborne pests (weeds, pathogens, and nematodes) and yield of ornamental crops in field evaluations. The results of this work will help growers and fumigant applicators make decisions on which alternative fumigation practices to use.

Anticipated Product 1D-4: *Technology transfer program to deliver concepts, assessments, and technologies needed for adoption of methyl bromide alternatives.*

> Accomplishments for this Anticipated Product have been combined with Anticipated Product 1D-7: *Model for areawide management of soilborne pests that can be utilized beyond initially targeted locations and commodities.*

Anticipated Product 1D-5: *A list of the sources of variability that affect the performance of methyl bromide alternatives.*

> Accomplishments for this Anticipated Product have been combined with Anticipated Product 1D-7: *Model for areawide management of soilborne pests that can be utilized beyond initially targeted locations and commodities.*

Anticipated Product 1D-6: *A knowledge base of the relationships between pest complexes and methyl bromide alternatives.*

Effects of management strategies on weed/nematode interactions. ARS researchers conducted three greenhouse and three field experiments that assessed rootknot nematode/weed interactions. The replicated controlled greenhouse studies evaluated 19 plant species, including weeds and cover crops, to determine susceptibility to three major *Meloidogyne* species, *M. incognita*, *M. javanica*, and *M. arenaria,* and to determine relative nematode reproductive rates on each plant species. Plant species differed in their susceptibility to each of the species of rootknot nematode, and in their susceptibility relative to each other. Data were also collected from three field trials evaluating alternative nematode and weed management strategies in vegetable and ornamental crops, including alternative fumigants such as iodomethane and dimethyl disulfide, and integrated approaches employing organic amendments and soil solarization. In field trials, rootknot nematode galled weeds were identified and females were extracted from roots and identified. The predominant species of rootknot nematode isolated from weeds in the field was *M. incognita*.

Interaction between lesion and rootknot nematodes in peach. Preplant fumigation is currently recommended for managing rootknot and lesion nematodes in peach in the southeastern United States. Furthermore, information on interactions between different nematodes co-inhabiting the same orchard is essential to understanding their combined impact on disease. ARS scientists conducted a 26-month field study to determine the interaction between the rootknot and lesion nematodes as related to peach tree growth. Results indicated that the rootknot nematode suppressed tree growth in peach more than lesion nematode and illustrated the pathogenic relationship between two economically important nematodes. Progress is being made in the use of a preplant groundcover that suppresses both nematode populations prior to orchard establishment.

Alternative to soil fumigation for control of apple replant disease. ARS researchers evaluated the efficacy of brassicaceae seedmeals for the control of apple replant disease and the effects of such treatments on the causal pathogen complex. Tree growth and fruit yield were examined over a 5-year period in conventional production systems. When applied independently, all preplant seedmeal treatments or a postplant mefenoxam failed to enhance tree growth or control disease to the level attained in response to soil fumigation. Postplant mefenoxam treatments revealed that failure of seedmeal amendments to enhance tree growth and yield when used independently was due, primarily, to increased apple root infection by *Pythium* species in *Brassica napus* and *Sinapis alba* seedmeal amended soils, and by *Phytophthora cambivora* in *Brassica juncea* amended soil. When used in conjunction with a postplant application of mefenoxam, *B. juncea* and *S. alba* seedmeal preplant soil amendments were as effective as preplant 1,3-D-chloropicrin soil fumigation in terms of disease control, vegetative tree growth, and 5-year fruit yields of Gala/M26 apple. Since these trials utilized the highly susceptible rootstock M26, the results demonstrate that this integrated strategy is a viable alternative to soil fumigation for the control of apple replant disease in conventional production systems.

Anticipated Product 1D-7: *Model for areawide management of soilborne pests that can be utilized beyond initially targeted locations and commodities.*
*(*Also incorporates Anticipated Products 1D4 and 1D5.*)*

Methyl Bromide Alternatives, Areawide Pest Management Project. In FY 2007, ARS initiated the Methyl Bromide Alternatives-Areawide Pest Management (MBA-AWPM) Project to facilitate growers' adoption of technologies for soil pest and pathogen control developed by ARS scientists and their collaborators from research conducted over the previous 10 years. The MBA-AWPM Project was established with emphasis on the western and southeastern United States, where agriculture was heavily dependent on methyl bromide as a soil fumigant. In addition to facilitating the transfer of methyl bromide alternatives to growers and institutions representing industries most affected by the phase-out of methyl bromide, the project sought to improve performance of the alternatives by:

- Identifying variables that most impact their efficacy and the means to manage it;
- Determining which supplemental methodologies could be incorporated to improve efficacy; and,
- In California, determining the best practices for the use of these alternative technologies to meet regulatory restrictions and increase farmer work safety.

To accomplish this, ARS scientists established collaborations with scientists at Auburn University, Clemson University, the University of Georgia, North Carolina State University, the University of Florida, the Florida Fruit and Vegetable Association, the Florida Tomato Exchange and others in the southeast, and with the University of California, the California Department of Pesticide Registration, and the California Marketing Order Boards in the west. Regionally specific demonstration trials were also established.

<u>Western Trials</u>

- ***Methyl bromide alternatives for cut flower and bulb production***. ARS scientists, in collaboration with university researchers, completed multiple, statewide research and demonstration trials in commercial California plantings of *Ranunculus* (field operations) and in iris, freesia, and snapdragon (enclosed operations) to test drip applications of chloropicrin and combinations of chlorpicrin with 1,3-D and metam sodium as alternatives to shank and hot gas applications of methyl bromide. The trials demonstrated to growers that the drip-applied alternatives provide pest control and crop yields equal to or better than those obtained with the conventional methyl bromide treatments. This work resulted in commercial transition to drip alternatives for cut-flower and bulb production and is reducing reliance on methyl bromide. Fumigant emissions are significantly lower following drip fumigation than following shank and hot gas fumigation.

- ***Methyl bromide alternatives optimized for production of perennial fruit, tree nut, and rose nurseries***. To optimize Telone II (1,3-D) reliability and reduce its atmospheric emissions, ARS researchers evaluated the efficacy of dual-depth injection of Telone II through extended-length, winged shanks; sprinkler-applied water seals; and VIF. VIF reduced fumigant emissions while maintaining or improving weed and pathogen control, but sprinkler-applied water seals and extended shanks were less effective. Improved VIF plastic mulch was validated for the nursery stakeholders as an effective tool to maximize performance of Telone II while minimizing its emissions.

- ***Effective methyl bromide alternatives for raspberry nursery stock production***. Raspberry nurseries have relied on preplant fumigation with methyl bromide to produce approximately 7 million plants annually for an annual fruit crop worth about $278 million. ARS researchers, in collaboration with university scientists, evaluated fumigant alternatives to methyl bromide (e.g., Inline®, Telone C35®, Midas®) and plastic mulch sealing films at an experiment station and three commercial raspberry nurseries in California and Washington. Several of the fumigants were as effective as the methyl bromide standard for raspberry plant production and pest and pathogen control. The efficacy of the alternative fumigants was improved when used with VIF. Solarization was not as effective in controlling raspberry plant pests or pathogens as methyl bromide plus chloropirin. Telone C35®, especially in combination with VIF, was validated as an effective methyl bromide alternative for raspberry nursery stakeholders.
- ***Methyl bromide alternatives for production of forest nursery seedlings in the western United States.*** Each year well over 300 million seedlings are grown for regeneration purposes in the southeastern and western United States. Although fumigant alternatives have been partially successful in replacing methyl bromide for this production system, regulatory stipulations are reducing allowed soil application rates and increasing the size of surrounding non-treated buffer zones for the alternative fumigants. At three forest nurseries, ARS and university scientists determined that reduced rates of alternative fumigant mixtures of chloropicrin plus 1,3-D were as effective as full-rate treatments with methyl bromide in reducing soilborne pathogen and weed populations. They also characterized the identity and pathogenicity of previously uninvestigated populations of *Pythium* species affecting forest nursery seedling production in the western United States. The effective alternative treatments and the new knowledge on contributions of *Pythium* species to disease losses in forest nurseries are being implemented in the management of commercial forest seedling nurseries in the Pacific Northwest.
- ***Methyl bromide alternatives optimized for almond and peach orchard replant.*** Preplant soil fumigation with 1,3-D has been widely used as a methyl bromide alternative for almond and peach orchard replant, but the treatment has not been completely effective for control of *Prunus* replant disease, and reductions in non-target fumigation emissions are being required. In a series of almond and peach replant trials, ARS researchers demonstrated that preplant shank fumigation with mixtures of chloropicrin plus 1,3-D improves control of replant disease and improves yields, compared to treatments with either methyl bromide or 1,3-D alone. Furthermore, GPS controlled spot shank fumigation and drip spot fumigation, each of which limit fumigation treatments to tree planting sites where they are most needed, were developed. ARS researchers, in collaboration with university colleagues, demonstrated that spot treatments can reduce both fumigant costs and fumigant emissions while achieving adequate control of *Prunus* replant disease. Tree growth

and yields continue to be monitored in long-term orchard replant trials to economically assess the effects of alternative spot, strip, and broadcast preplant fumigation treatments; short-term preplant crop rotations with Sudan grass; and alternative rootstocks.

- ***Integration of alternative fumigants with improved plastic mulches for replacement of methyl bromide for strawberry production***. ARS scientists, in collaboration with university researchers and commercial strawberry growers, completed multiple research and demonstration trials across California's coastal strawberry production districts to compare reduced rates of drip-applied fumigant alternatives to methyl bromide in combination with low permeability plastic mulches. The trials demonstrated to growers that low rates of fumigant alternatives, i.e., combinations of chloropicrin with 1,3-D, if applied under low permeability plastic mulch, can be used to obtain strawberry yields equivalent to those from conventional treatments with methyl bromide-chloropicrin combinations. Furthermore, data were obtained to confirm that the low permeability mulches retain fumigants in soil longer than conventional high density polyethylene mulches, thereby improving fumigant efficacy near the soil surface and reducing atmospheric emissions. This research also demonstrated the feasibility of gluing impermeable films for broadcast fumigation. This work has provided strawberry growers with valuable alternatives to methyl bromide that are effective and conducive to use under current regulatory restrictions.

<u>Southeastern Trials</u>

- ***Alternatives to methyl bromide demonstrated in key crop systems and regions formerly dependent solely upon methyl bromide***. ARS scientists, along with university collaborators, conducted 48 large-scale field demonstration trials, using the best available, industry appropriate alternatives to methyl bromide. The alternatives included substitute fumigants and supporting IPM practices. Trials were conducted in partnership with commercial growers at sites adequately representing the biological and environmental diversity of the production systems of tomato, pepper, eggplant, strawberry, forest nursery seedlings (loblolly pine), sod, ornamentals (caladium), and cut flowers (delphinium). Grower demonstration trials were performed in Alabama, Florida, Georgia, South Carolina, and North Carolina. The size of each grower's demonstration trial ranged from 0.5 to 58 acres. These trials demonstrated that technically feasible alternatives to methyl bromide soil fumigation are available and can control pests adequately without the environmentally damaging effects of methyl bromide.

- ***Key variables and their critical values responsible for consistent and effective pest control and crop productivity with methyl bromide alternatives***. Variability in soil fumigant levels, pest control, and/or marketable yield was observed in many of the large-scale field demonstration trials. In five trials where pest control was compromised, the methods and equipment used to apply soil fumigants were identified as the key factors responsible for variability in fumigant performance. Environmental conditions (soil moisture, bulk density, and temperature) combined with an excessive fumigant application rate were identified as the key variables affecting fumigant performance in an additional four trials.

- ***Soil fumigant emissions studies in commercial tomato production regions of Florida and Georgia***. ARS scientists, with university collaborators, private industry, and the EPA, conducted soil fumigant flux studies to generate data on fumigant emissions, using improved application methods and equipment. In addition, they collected data suitable for determining if emission models can be used to extrapolate the results beyond the specific soil type and soil conditions that were directly evaluated. 1,3-D, chloropicrin, and the methyl isothiocyanate generators (metam sodium and metam potassium) were co-applied in the study under three different shank application scenarios. Field flux rates were computed using the integrated horizontal flux method as the primary method. Off-field air monitoring and regression analysis with normalized dispersion modeling was used to compute flux rates during the active application periods. The methodology used in this field study was found to adequately characterize the emission rates for the three fumigants tested in these treatment plots. The emission rates were low for all treatment plots and all fumigants. These results are attributed to sound soil moisture management. This factor, coupled with the use of high barrier tarp materials (VIF and metalized film) resulted in well-controlled applications in terms of flux loss. Total loss rates across all three fields and all fumigants ranged from 0.08 percent to 10.96 percent.
- ***Multi-regional education programs for growers, farm workers, and associated members of the agricultural community***. ARS researchers, in collaboration with university colleagues, designed and constructed an apparatus to simulate calibration and operation of fumigation application equipment in an instructional setting using water instead of chemical fumigants. The researchers used this apparatus to demonstrate application procedures affecting fumigant performance to 21 commercial tomato production managers, county extension agents from Florida, Georgia, South and North Carolina, and members of the Southern Forest Nursery Management Cooperative. A 2-day regional workshop was held at the University of Georgia Tifton Campus to train cooperative extension faculty from six universities in the southeastern United States on the application of methyl bromide alternatives. Experts from around the southeast provided updates regarding the implementation of alternatives and taught the proper calibration and operation of fumigation application equipment.
- ***An educational platform for compliance with the new Fumigant Re-registration and Eligibility Decision issued by the EPA.*** To facilitate compliance with the 2010 Fumigant Re-registration and Eligibility Decision issued by the EPA, ARS researchers and collaborators created a soil fumigation manual. This manual contains information on the new soil fumigation regulations, methods for proper soil fumigant application that maximizes safety, and efficacy including equipment calibration and safety procedures. The manual will be available in southeastern states for training. ARS researchers and collaborators created a set of 10 PowerPoint presentations to integrate with the soil fumigation manual. Presentations are being developed to facilitate state cooperative extension trainings for stakeholders on the new fumigant regulations and will be tailored to provide continued education credits for those states that add or update their pesticide licensing to include a soil fumigation category. A set of 11 online interactive training modules were created as a stand-alone training

aid. The modules are linked to a database housed on the University of Florida's Institute of Food and Agricultural Sciences' extension server to allow traceability of certification to meet the requirements of EPA on determination of proper training. Beta testing of the completed training modules was conducted in stakeholder workshops.

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COMPONENT 2: POSTHARVEST ALTERNATIVES

In addition to preplant applications, methyl bromide is used as a postharvest fumigant to disinfest agricultural processing and storage structures, to preserve the quality of both perishable and durable commodities by killing pests, and as a quarantine treatment to prevent the undesirable movement of insects, pathogens, and nematodes that could be transported with commodities and wood packing material. CUEs have been granted for the postharvest use of methyl bromide where alternatives are perceived to be lacking in efficacy; too expensive, slow acting, or corrosive; or when fast turn-around is needed. CUEs have also been used when regulatory issues prevent use of alternatives. Quarantine use of methyl bromide is currently exempted from the phase-out under the Montreal Protocol. In many cases, methyl bromide is the only approved quarantine treatment to allow movement of a commodity in international trade, and its loss would mean the potential loss of hundreds of millions of dollars in imports and exports of fruit, vegetables, and nuts; as well as other commodities shipped with wooden packaging. ARS research projects under this component are working to reduce the need to fumigate and to develop potential chemical and non-chemical replacement treatments for postharvest uses of methyl bromide.

Engaged ARS Locations: Parlier, California; Salinas, California; Gainesville, Florida; Miami, Florida; Hilo, Hawaii; Manhattan, Kansas; and Weslaco, Texas.

PROBLEM STATEMENT 2A: DEVELOPING ALTERNATIVES TO METHYL BROMIDE FOR DISINFESTATION OF POSTHARVEST FOOD-PROCESSING FACILITIES.

Problem Statement: Structures where food is processed and stored, such as flour mills and warehouses, need to be maintained in a manner that minimizes the risk of the food becoming adulterated with insects, because of both regulatory and consumer demands. Stored-product pests can inhabit hidden and hard-to-reach areas in buildings, and move from these areas to infest food products; thus, there is a need for a management tool, such as a fumigant, that can penetrate into these areas. Structural fumigation with methyl bromide was typically conducted on a calendar basis during normal holiday plant closings because of the need to shut down production during fumigation. As a response to the phase-out of methyl bromide, those responsible for pest management in these facilities are relying more heavily on monitoring insect populations to determine when to fumigate, rather than calendar-based fumigation, adopting other management tactics to reduce the need for fumigations, and exploring other alternative structural treatments.

Alternative structural treatments, including alternative fumigants, are available for the management of stored-product insect infestations of food facilities, but how effective these alternatives are compared to methyl bromide is not well understood. Phosphine is a widely used fumigant for bulk-stored products, but its use in food facilities is limited because it causes corrosion to electronic circuits. The fumigant sulfuryl fluoride has been registered for use in structural facilities, but efficacy studies are still needed to optimize its use in different types of facilities and to determine its economic feasibility. No other fumigants are currently registered for postharvest structural treatments. Research to define the efficacy and environmental effects

on that efficacy will be investigated to gain a better knowledge of the important parameters involved and the basic efficacy of alternatives.
A variety of management tactics can be used to delay the need for fumigation, including sanitation and structural modification, heat treatments, spot treatments with insecticides, and aerosol foggings. An important question is how best to integrate these tactics into an integrated or systems approach that can reduce the need for whole structure treatments.

Research Needs: Knowledge about how alternative fumigants compare to methyl bromide needs to be expanded in terms of their efficacy and impact on commodity quality. Efficacy needs to be understood under both controlled laboratory conditions, where the relationships among fumigant concentration, time, environmental conditions, pest species, and stage need to be determined, and in the field, where factors such as gas distribution, pest population density and distribution, and environmental and structural conditions influence efficacy. Systems approaches or IPM strategies have the potential to reduce the need for structural fumigations, but how best to implement these approaches needs to be determined.

Anticipated Products:

- Efficacy matrix including, for example, fumigant concentration, exposure time, temperature, pest species, and life stage that compares methyl bromide with alternative fumigants in laboratory tests.
- A knowledge base of field validation data of alternative fumigants and assessment of factors influencing efficacy.
- An evaluation of the impact of different systems approach/IPM techniques at reducing the need for structural fumigations.

PROBLEM STATEMENT 2A: ACCOMPLISHMENT SUMMARY

Research conducted under this Problem Statement seeks to develop effective methods for disinfesting food-processing and storage facilities. Flour beetles and moths are the primary targets, although lice are also pests of stored products. Control measures in development include physical (heat), sanitation, natural and synthetic insecticides, insect growth regulators (IGR), and attractants for trapping. Insect behavior was also studied to optimize deployment of control measures. This research has resulted in the availability of new products for management of pest infestations in structures and label modifications of existing pesticides to include structural disinfestation uses.

PROBLEM STATEMENT 2A: SELECTED ACCOMPLISHMENTS

Anticipated Product 2A-1: *Efficacy matrix including, for example, fumigant concentration, exposure time, temperature, pest species, and life stage that compares methyl bromide with alternative fumigants in laboratory tests.*

> ***Cigarette beetle egg stage most tolerant to heat treatments.*** Heat treatments are a potential alternative to methyl bromide for disinfestation of structures, but little

information is available on their effectiveness against the cigarette beetle, a pest associated with food-processing facilities. ARS and university scientists evaluated the susceptibility of all cigarette beetle developmental stages to elevated temperatures. These scientists determined that the egg stage was the most heat tolerant stage, and that the time to kill 99 percent of eggs was 190 minutes at 122°F. Determining the most heat tolerant stage provides the target temperatures and exposure times for managers and pest control professionals using heat treatments to control cigarette beetles in food-processing facilities.

Control of psocids (booklice) in flour mills with sulfuryl fluoride. Sulfuryl fluoride is among the most promising alternative fumigant insecticides for control of insects in flour mills. Psocids are pests of stored grains and grain products and have natural tolerance to some of the insecticides used for control of stored-product insects. ARS researchers evaluated sulfuryl fluoride for control of different life stages of four species of psocids (*Liposcelispaeta entomophila*, *L. bostrychophila*, *L. decolor*, and *Lepinotusreticulatus)*. Adults and nymphs were killed by sulfuryl fluoride applied at the label rate, but some eggs survived. This information can be used by flour millers and pest control operators to determine whether sulfuryl fluoride will provide control of psocid populations in flour mills.

Anticipated Product 2A-2: *A knowledge base of field validation data of alternative fumigants and assessment of factors influencing efficacy.*

Sulfuryl fluoride fumigation reduces red flour beetle populations in rice mills. ARS researchers monitored red flour beetle in four rice mills, before and after nine fumigations with sulfuryl fluoride. After treatment, there was a reduction of 81 percent in the average number of beetles captured per trap and an average reduction of 63 percent in the probability of capturing a beetle in a trap. These results are similar to those reported for methyl bromide fumigation in wheat mills. After fumigation, population rebound rates in rice mills tended to be slower than in wheat mills, but this may reflect differences in the population growth potential in these two types of mills. Understanding how structural fumigations impact pest populations is important for both the assessment of methyl bromide alternatives and the development of more effective IPM programs.

Rebound in red flour beetle following flour mill structural fumigations. More effective management of the rate at which pest populations recover following structural fumigations of food-processing plants, could reduce the need to fumigate and make methyl bromide alternatives more viable. Evaluation by ARS scientists of data from 21 fumigations in two mills indicated that both the time of year fumigation was performed and the IPM practices that were used within the mill after fumigation affected rebound time, as measured by the time it took for beetle captures to increase to different thresholds. A new monitoring threshold was developed that can be applied as a management target to reduce risk. These findings provide baseline information on methyl bromide efficacy and illustrate how population growth can be manipulated to reduce the need to fumigate.

Simulation model for red flour beetle in flour mills to evaluate fumigation efficacy. Red flour beetle contamination of flour has many negative impacts on the milling industry including damage to brand identity, failure to pass inspections, and the cost of product returns. ARS scientists developed a computer model for the red flour beetle in flour mills, which can be used to predict the effects of several fumigation strategies. Insect population rebound following fumigation in the fall occurred more slowly over a longer period of time than following spring fumigations. Simulated fumigations with sulfuryl fluoride resulted in faster population rebound than methyl bromide as a due to reduced egg mortality in the former. Findings from this study will be used to develop optimal treatment programs for flour mills, using alternative methods such as heat and sulfuryl fluoride.

Anticipated Product 2A-3: *An evaluation of the impact of different systems approach/IPM techniques at reducing the need for structural fumigations.*

Monitoring and Trapping

Effective pest monitoring is critical to pest management systems to provide the necessary guidance for timing and targeting the application of control measures. Monitoring and control of red flour beetle, a major pest of food-processing and storage facilities, often relies on traps with chemical cues such as pheromones and food. There is considerable variation in the environment among the trap locations, which could impact the effectiveness of traps at capturing red flour beetles, which typically disperse by walking or by short flights. ARS research addressed several of these issues.

- ***Novel red flour beetle trap developed.*** ARS researchers developed a new trap for monitoring the red flour beetle that uses ultraviolet light, a chemical attractant, and a physical configuration that guides beetles into a pitfall. In small-scale experiments, trap efficiency was estimated to be about 33 percent, i.e., the trap captured one third of the flour beetles present. This is a comparatively high efficiency, indicating promise as a monitoring tool for use in flour mills and other food-processing plants.
- ***Natural pheromone blend and site of production for red flour beetle.*** Although the commercial attractant, “Tribolure,” has long been used for monitoring populations of flour beetles, the physiological site of production and the natural blend of stereoisomers in the insect-produced attractant were unknown. ARS scientists, with university cooperators, demonstrated that the natural pheromone is produced in the red flour beetle’s abdominal epidermis and is composed of a 4:4:1:1 ratio of the four forms of 4,8-dimethyldecanal. They also demonstrated that this natural blend is significantly more attractive than Tribolure, which is a 1:1:0:0 ratio of the four forms of 4,8-dimethyldecanal.
- ***Changing the color of the background behind a pheromone trap increases red flour beetle response***. ARS scientists, with university collaborators, determined in laboratory studies that beetles respond to tall black shapes and more beetles were captured in traps with black backgrounds than those with white backgrounds. These findings suggest that trap effectiveness could be increased using a relatively simple and inexpensive modification of the walls behind the trap, although validation of this

increase in effectiveness is still needed in the more complex environments inside food facilities.

- ***Influence of location within flour mill on effectiveness of red flour beetle traps.*** ARS researchers, with university collaborators, showed that patterns of beetle capture were highly variable within the mill, and that the beetles tended to follow patterns of shifting distribution among floors over time after fumigation; this resulted in limited influence of local factors on trap captures. Trap locations with greater beetle captures tended to be associated with warmer temperatures, more spillage accumulation, and close proximity to processing equipment, but this association was relatively weak. Although certain factors could be used by pest management professionals to select trap locations, focusing just on these areas could be misleading, given the long term patterns of change in distribution over time.

- ***Red flour beetle ability to move among floors in flour mill.*** ARS scientists, with university cooperators, used self-mark and recapture techniques to show that beetles were able to move among floors, typically downward, even in a mill that is relatively tightly sealed between floors. Heat treatments applied for insect control drove insects from hidden refugia, but did not increase movement among floors. These results suggest that red flour beetles may be more mobile within flour mills than was originally suspected and may impact determination of the sources of insects captured in traps and in modeling population dynamics.

Aerosolized Applications

Pest management professionals have begun using aerosolized insecticide applications more frequently to mitigate stored-product insect infestation in food-processing facilities and storage warehouses. Aerosol insecticide applications of pyrethrin mixed with methoprene, an insect growth regulator (IGR), are being used with increasing frequency inside flour mills. IGRs cause the death of immature insects, and survivors may have reduced fitness. In addition, residual activity of these insecticides can be impacted by the substrate to which they are applied. ARS research addressed the efficacy and residual activity of various treatments, as well as the factors that can hinder treatment performance.

- ***Insecticide combination to control Indianmeal moth eggs and larvae***. ARS scientists evaluated two registered insecticides for their ability to control eggs and late-stage larvae of the Indianmeal moth. Methoprene, an IGR, was effective on larvae, but not as effective on eggs. Esfenvalerate, a pyrethroid, was not effective on larvae, but demonstrated some control on eggs. Using these insecticides in combination gave more complete control of eggs and larvae. A cost/benefit economic analysis showed that adding methoprene increased treatment effectiveness and did not appreciably increase the cost of insecticide application.

- ***Field trials show effectiveness of aerosols***. ARS scientists conducted several field trials by exposing eggs of the Indianmeal moth that were either in foods or on packaging materials to treatments of pyrethrins applied alone and in combination with methoprene. Results show that the aerosols penetrated underneath pallets, and the combination of pyrethrin and methoprene was optimal for best control of eggs with the lowest cost. There was some variation depending on the specific diet of the Indianmeal moths or the type of packaging material exposed, but overall results showed that the aerosols could be used to control the eggs of the Indianmeal moth in a commercial facility.

- ***IGRs reduce potential for red flour beetle population growth.*** Exposure of red flour beetle adults to wheat treated with an IGR did not reduce their subsequent reproduction. However, male larvae that were exposed to an IGR were less likely to survive to the adult stage than female larvae. In addition, male larvae that survived exposure to an IGR and reached adulthood produced less offspring than unexposed males. Non-lethal effects of an IGR, in addition to the lethal effects, could increase the impact of these insecticide treatments on population growth rates of red flour beetle.

- ***Differences in aerosol insecticide residual control among pest species suggest different application rates should be used***. ARS scientists and university cooperators exposed flour in petri dishes to applications of either low (1 percent) or high (3 percent) rates of pyrethrin and methoprene, then measured the survival of immature red flour beetle and confused flour beetle at 2 week intervals. Results show that if the red flour beetle is the target species, the low rate of pyrethrin and methoprene was sufficient, but if the confused flour beetle is the target pest the higher rate is preferable.

- ***Flour deposits and obstructions impact treatment efficacy against red flour beetle***. Pilot-scale tests of two aerosolized insecticides (pyrethrins and esfenvalerate) on all life stages of the red flour beetle demonstrated that insect mortality generally decreased as the amount of residual food (flour) increased, and mortality was reduced if the insects were sheltered. Differences in beetle mortality between insecticides were considerably less than differences attributed to flour deposits, suggesting that sanitation and removal of obstructions prior to aerosol insecticide treatments was more important than the choice of a particular insecticide. In similar studies, ARS scientists, in collaboration with university researchers, found that the protective effects of flour residues on insect mortality during heat treatment were much greater for adults than for eggs. Flour depths of 1 inch or greater had less than 10 percent adult mortality; demonstrating the importance of sanitation prior to heat treatments in flour mills.

Repellants and surface treatments

Treatments that delay pest infestation or re-infestation can play a role in reducing the number of fumigations needed to control insects in food-processing facilities. There is a need for insect repellants that reduce insect attraction to these facilities and surface treatment insecticides that control stored-product insects inside processed food facilities. Insect repellents are used in a wide range of pest management programs, but few are available for stored-product insects.

- ***New IGR controls stored-product insects***. ARS scientists demonstrated that NyGard® (pyriproxyfen), a new IGR recently labeled by the EPA for use as an aerosol and a surface treatment inside mills and food-storage warehouses, generally gave greater residual control of four beetle species and the Indianmeal moth, than Gentrol®, another IGR. NyGard® performed better than Gentrol® on plywood, metal, and tile treated surfaces. The Indianmeal moth larvae were generally more tolerant to both insecticides than the beetle larvae, but there were variations in susceptibility among the different beetle species. This work demonstrated that NyGard® was effective and could be used as a residual surface treatment in management programs for control of stored-product insects.

- ***New insecticide to control stored-product beetles.*** Phantom® is a new insecticide that specifically targets insect metabolism and is registered to control termites, cockroaches, and ants, but not stored-product insects. ARS scientists compared the exposure of adult red flour beetles and confused flour beetles on concrete, tile, and plywood surfaces treated with Phantom®. The insecticide was more effective on concrete than tile and plywood, and the red flour beetle was more susceptible to Phantom® than the confused flour beetle. This insecticide can be incorporated into management plans for stored-product insects in food-processing facilities. The insecticide label is being amended to include control of these stored-product insects.
- ***Catmint oil potential as a repellent for flour beetles***. ARS scientists evaluated two types of oils made from catmint plants as repellents for the red flour beetle and the confused flour beetle. Video recordings showed that both oil products were more repellent to the red flour beetle than to the confused flour beetle. Red flour beetles would avoid the area that was treated with these oils, demonstrating that catmint oil products are effective repellents for the red flour beetle. These results will be of value to managers of stored products looking for effective alternatives to synthetic pesticides to prevent red flour beetle infestations.

Insect Biology

Understanding basic insect biology is crucial to developing long-term, sustainable alternatives, to methyl bromide fumigation. This research is conducted by projects that contribute to NP 308, but are not managed as a part of this Program. These accomplishments are presented to give the reader a more complete understanding of the breadth of ARS research that supports the search for technically and economically feasible alternatives to methyl bromide.

- ***Genomic sequencing of the red flour beetle completed***. The red flour beetle is a significant pest of stored grain and grain products, and the most important insect pest in flour mills. It can survive on a wide range of foods, including cornmeal, nuts, crackers, cake mix, and even chocolate. ARS scientists, and university collaborators, sequenced the first beetle, *Tribolium castaneum* (red flour beetle), which joins the ranks of other fully sequenced "model organisms" such as the *Drosophila* fruit fly and the honey bee. This sequenced genome may provide clues to help thwart this important agricultural pest, provide insight into the red flour beetle's ability to establish resistance to many classes of insecticide, and ultimately open new doors to insect pest management strategies in general.

- ***Insect "yellow" genes characterized.*** Some of the most effective insecticides available are IGRs that interfere with molting processes. ARS scientists identified 14 new genes in the red flour beetle that likely have roles in the maturation (hardening and darkening) of the insect cuticle. Inhibiting the expression of some of these genes resulted in failure of the exoskeleton to either darken or ripen normally. In some cases such gene knockouts prevented the affected insects from shedding their old exoskeleton, resulting in death of the insect. In another study, ARS scientists identified two new uridine diphosphate N-acetylglucosamine pyrophosphorylase genes (UAP genes) in the red flour beetle, genes that are required to generate the basic building blocks of chitin, a major component of the insect exoskeleton. One of the UAP genes is unique to red flour beetles and functions in nutrition and growth. The disruption or elimination of this unique UAP gene resulted in insect death, apparently by starvation, providing proof that the disruption of specific genes can be lethal to insects. Knowledge of this vulnerability could be utilized to develop new pesticides specific to the red flour beetle.

PROBLEM STATEMENT 2B: DEVELOP ALTERNATIVES TO METHYL BROMIDE FOR DISINFESTATION OF POSTHARVEST DURABLE COMMODITIES.

Problem Statement: For many years, methyl bromide has been used for the treatment of durable commodities, such as dried fruits, tree nuts, dried beans, and others, to disinfest field and storage pests before marketing domestically and abroad. Because these commodities often remain in storage for months, or even years, before reaching consumers, multiple treatments may be necessary, creating a need for quick, effective, inexpensive treatments and management practices that reduce the frequency of treatments. For some commodities, rapid disinfestation treatments must be used to allow the product to reach time-sensitive markets. In the walnut industry, for example, it has been widely used to eliminate insects from shipments of in-shell nuts going to the United Kingdom and Japan for the November and December holiday season. Nuts harvested in September and October are quickly processed to meet this need, and these nuts are a significant share of the total worldwide market for walnuts. The great variety of processing and storage methods used for these diverse commodities suggests that a variety of alternatives must be developed.

For durable commodities such as dried fruit and nuts, chemical treatments being investigated include new chemicals such as Profume (sulfuryl fluoride), propylene oxide, and new techniques using phosphine at cold temperature. Non-chemical alternatives for durable commodities that will be researched include infrared heating, cold, a new Controlled Atmosphere Temperature Treatment System or CATTS (hot air plus controlled atmosphere) for fresh fruit, and compression combined with phosphine for treatment of hay going to Japan. Other technologies are in various stages of research and may add to the growing list of potential treatments. In addition to chemical and physical treatments, IPM methods that eliminate pests in the field before they infest fruit or nuts are being investigated.

Research Needs: Knowledge about how alternative fumigants compare to methyl bromide in terms of efficacy and how they impact product quality will be extended to durable commodities. For alternative fumigants, the relationships among concentration, time, environmental conditions, pest species, and stage need to be determined, as well as how factors such as gas distribution, pest population density and distribution, and environmental and structural conditions influence efficacy. The efficacy of physical treatments, such as heat treatments, cold storage, vacuum, and irradiation, will be evaluated as alternatives for potential applications. IPM strategies and biorational methods for controlling field pests of phytosanitary concern have great potential for reducing the need for commodity fumigation, but implementation of these techniques requires greater knowledge of insect behavior and population biology.

Outputs:

- Efficacy matrix including, for example, fumigant concentration, exposure time, temperature, pest species, and life stage that compares methyl bromide with alternative fumigants in laboratory tests.
- A knowledge base of field validation data of alternative fumigants and assessment of factors influencing efficacy.
- Physical treatment parameters for the most tolerant target pests, with efficacy of the most promising physical treatments under commercial conditions.
- Models for predicting field pest population growth and evaluating the effect of management practices on pest pressure.
- More effective monitoring methods, including improved pheromone lures, for use by the models.
- IPM strategies which include biorational control methods, such as mating disruption, natural enemies, and pathogens.
- Enhanced methodologies to capture methyl bromide being used under CUEs or QPS Exemptions.

PROBLEM STATEMENT 2B: ACCOMPLISHMENT SUMMARY

Research conducted under this Problem Statement seeks to develop effective methods for disinfesting durable commodities, such as dried fruits, tree nuts, and dried beans, before marketing domestically and abroad. ARS scientists developed treatments based on alternative fumigants; non-fumigant chemicals; and physical treatments, such as heat, vacuum, and ultra-low oxygen. Determination of the most tolerant insect life stage for postharvest treatment, as well as the conditions in the field that can influence either the population dynamics of the insects or the efficacy of in-field treatments, are critical aspects to optimizing pest management in durable commodities. This research has resulted in new products, characterization of the efficacy of existing products, documentation of efficacy of quarantine treatments and the level of risk in exporting a quarantine pest, and models to improve management decisions. One area of research, methyl bromide recapture, was postponed due to retirement of key personnel.

PROBLEM STATEMENT 2B: SELECTED ACCOMPLISHMENTS

Anticipated Product 2B-1: *Efficacy matrix including, for example, fumigant concentration, exposure time, temperature, pest species, and life stage that compares methyl bromide with alternative fumigants in laboratory tests.*

Toxicity of sulfuryl fluoride to insect eggs as compared to other life stages. Insect eggs can be the most difficult stage to kill and care must be taken to ensure a fumigant's effectiveness on this life stage. ARS scientists assayed Indianmeal moth (a pest of stored corn), red flour beetle, and dried fruit beetle for sensitivity to sulfuryl fluoride. In all instances, eggs were the most tolerant stage of the insect. Some species required very high doses of sulfuryl fluoride to kill the eggs, which will make it expensive to use in some cases and render it inefficacious in others. This work is the most comprehensive tool for indexing the potential utility of sulfuryl fluoride fumigations, relative to established methyl bromide protocols, for controlling insect pest infestations of stored dried fruit and nuts, so that domestic and international distribution is maintained.

Persistence of beta cyfluthrin, bifenthrin, and methoxyfenozide in almonds and pistachios. Greater knowledge is needed regarding the persistence of currently used and novel insecticides for the control of navel orangeworm in pistachios and almonds. ARS scientists demonstrated that methoxyfenozide persisted for 30 days in pistachios, bifentrhin persisted in almonds for 30 days, and beta cyfluthrin persisted in pistachios for 21 days. These findings will improve control of navel orangeworm by increasing the flexibility of insecticide application and provide additional insight for optimal treatment times.

Methyl bromide alternatives for insect control in walnuts. ARS scientists explored sulfuryl fluoride treatments for the navel orangeworm and the coddling moth, which are both critical problems for California walnut growers who export their crop. Using multivariate experimentation to probe probit-9 mortality scenarios, ARS scientists expedited the development of quarantine fumigation schedules. Empirical tests were then used for confirmation. The marked predictive and confirmatory power of multivariate experimental techniques in streamlining the development of biocidal treatments for structural, perishable, or durable commodities was reported for the first time in the context of postharvest chamber fumigation. This information was used by both the walnut industry and government during development of methyl bromide CUE nominations.

Quarantine strategies to control Hessian fly in exported hay. China, Hong Kong, South Korea, and South Vietnam are emerging markets for U.S. hay exports, and regulatory agencies seek new methods to ensure that the Hessian fly, a domestic pest, is not accidentally introduced to these countries through hay shipped from the western states. ARS researchers determined that hay harvesting and drying practices increased the mortality of Hessian fly puparia in warm and arid climates, where export quality hay is grown. In addition, fumigation with a phosphine and carbon dioxide gas mixture completely controlled this pest in laboratory tests. These findings support the position that the occurrence of Hessian fly in harvested, processed, and fumigated hay bales is negligible and protects a $660 million annual foreign market.

Anticipated Product 2B-2: *A knowledge base of field validation data of alternative fumigants and assessment of factors influencing efficacy.*

Navel orangeworm damage patterns in almonds. ARS scientists, in cooperation with the almond industry, found that damage to the almond crop (worth over $2 billion annually) from navel orangeworm declined greatly within the first 200-400 feet of 160-acre almond blocks and was homogeneous in the remaining interior parts. These results assure growers that they can control navel orangeworm populations in the interior portion of their blocks and demonstrate possible benefits of cooperative management of regional navel orangeworm populations for controlling this pest in the outer sections of the orchard.

Identify risk factors for navel orangeworm damage in pistachios. The navel orangeworm is the primary pest of pistachios in California. In 2007-2009, ARS scientists, and industry collaborators, obtained grade-sheets representing more than 65 percent of the entire harvest and determined the relationships between harvest date, shell integrity, and pistachio maturity. An additional year's data was gathered in 2010. Analysis of the entire dataset, which will provide information to improve control of this pest, is underway.

Anticipated Product 2B-3: *Physical treatment parameters for the most tolerant target pests with efficacy of the most promising physical treatments under commercial conditions*.

Effect of product moisture on efficacy of vacuum treatments. ARS scientists showed that at 25°C and 30°C, high moisture (9 percent) walnuts require longer vacuum treatment times than low moisture (6 percent) walnuts to completely disinfest them of Indianmeal moth, and that diapausing Indianmeal moths were more tolerant of vacuum treatments than non-diapausing larvae. Eggs were relatively unaffected by differences in relative humidity, and young eggs were often more tolerant than older eggs. This information has been used to develop more accurate treatment schedules. Commercial testing is needed to improve the adoption of vacuum treatments as a non-chemical alternative.

Determination of the most heat tolerant stage of the cowpea weevil. Cowpea weevils cause damage to leguminous crops, and pose a serious concern to export markets. Effective heat treatments require that the most heat tolerant pest stage be identified. ARS scientists used a heat block, developed by university collaborators, to determine that the late larval and pupal stages are the most heat tolerant stages of the cowpea weevil. This information was used to develop fast, non-chemical heat treatments, using radio frequency energy.

Ultra-low oxygen treatment for control of vine mealybug on grape rootstocks. The current method of controlling vine mealybug, a major pest of vineyards, by dipping dormant rootstocks in hot water after harvest, is labor intensive. ARS researchers developed an efficacious, ultra-low oxygen treatment that controls the pest, by storing rootstocks with vine mealybug under ultra-low oxygen treatment for 3 days at 25°C or 4 days at 15°C. The treatments caused 100 percent mortality of all life stages of vine mealybug and had no negative effects on rootstock growth providing a safe, effective, and economical control of vine mealybug.

Anticipated Product 2B-4: *Models for predicting field pest population growth and evaluating the effect of management practices on pest pressure.*

Assessment of the emergence of overwintering navel orangeworm. Numbers of overwintering navel orangeworm strongly affect the infestation level in new season pistachios, yet no assessment techniques are available to estimate overwintering populations. ARS scientists found that degree day emergence curves for navel orangeworm from lab-incubated, winter-collected pistachio mummies matched degree day trap capture curves in pheromone-baited traps, during spring emergence. Studies conducted in Madera and Fresno counties validated the emergence curves for pistachios and also established emergence curves for almonds. These data established the validity of using male trapping as a basis for in-season control decisions to improve navel orangeworm management, and decrease damage. Information on generation time and optimum time for application of selective insecticides has been presented to growers and pest control advisers in a series of presentations sponsored by the Pistachio Research Board; the NOW-AWPM project; industry; and the University of California Cooperative Extension Service.

Prediction of navel orangeworm damage to almonds using egg traps. Egg traps are currently used for timing insecticide application for navel orangeworm, a major pest of almonds, but not for prediction of damage. ARS scientists compared eggs per trap with damage in Monterey almonds that had a wide range of navel orangeworm damage. A significant association of high egg counts with subsequent damage was found, suggesting that threshold egg trap counts could be used as an early indicator of risk of high damage. These findings will refine integrated management of navel orangeworm in almonds, thereby protecting California's more than $2 billion dollar almond industry, while reducing insecticide use.

Development of a predictive model for navel orangeworm damage to Nonpareil almonds. ARS scientists and industry collaborators assessed the relative contribution of harvest date, previous year crop residue, and proximity to pistachios as contributors to navel orangeworm damage in Nonpareil almonds. These data were used to create a learning tool that is now hosted on the Web site of the Almond Board of California. This tool will improve control of navel orangeworm and help reduce the rejection rate of exported almonds. In addition, ARS scientists assessed the overwintering survival of navel orangeworm in five varieties of almonds as well as its development rate on each variety. ARS researchers also determined that the almond varieties Nonpareil and Butte supported the fastest development and greatest survival. Further studies revealed the importance of the almond variety Padre as a source of overwintering navel orangeworm. A more stringent sanitation standard for the San Joaquin Valley was presented to growers at the annual meeting of the Almond Board of California, as was a series of presentations, sponsored by the NOW-AWPM, industry, and the University of California Cooperative Extension Service. These studies will help reduce the standing population of navel orangeworm, thereby reducing insect damage and production costs.

Indianmeal moth simulation model developed and tested in stored corn. ARS scientists developed a computer model to simulate population development of the Indianmeal moth, a common pest of stored corn. The model accurately simulated population development in corn stored during fall and winter, of three separate storage seasons in South Carolina, but did not accurately predict populations in the spring. Despite this, the computer model could be useful from a management perspective, because the corn is being sold or used during the winter, and the observed Indianmeal moth populations never reached damaging levels after winter. The model will be useful for predicting Indianmeal moth population levels in stored corn to time management actions. The model will also be evaluated for its applicability to populations in food processing facilities.

Anticipated Product 2B-5: *More effective monitoring methods, including improved pheromone lures, for use by the models.*

***Collection of host volatiles for attraction of navel orangeworm*.** The almond oil volatiles that are currently used in traps to monitor navel orangeworm in the field are not always effective once the nuts in the field become susceptible to infestation. ARS scientists collected volatiles from susceptible and non-susceptible nuts and then analyzed them chemically and by behavioral bioassays to determine which compounds are attractive to navel orangeworm females. Isolation and characterization of these host volatiles will lead to better monitoring and/or direct control for this serious nut pest by inducing oviposition on unsuitable hosts.

Anticipated Product 2B-6: *IPM strategies which include biorational control methods, such as mating disruption, natural enemies, and pathogens.*

Efficacy of entomopathogenic nematodes applied by chemigation for navel orangeworm control. ARS researchers conducted studies using the registered product Millennium® to evaluate the large-scale application of insect pathogenic nematodes, using the irrigation system (chemigation), in almond and pistachio orchards located in the Central Valley of California. The studies successfully demonstrated that nematodes were an effective treatment for controlling insects, provided that sufficient water was available for application and post-application irrigation. Treatment was most successful when micro-sprinklers covered 80 percent of the plot area. The purpose of this research was to augment conventional postharvest sanitation and reduce overwintering populations of the navel orangeworm. This product is now being used in organic pistachio orchards.

Navel Orangeworm Areawide Pest Management Project. The navel orangeworm is an important pest of almonds and pistachios, an industry worth over $2.5 billion annually. In 2007, ARS initiated the Areawide Control Program for Navel Orangeworm-Areawide Pest Management (NOW-AWPM) project to develop and implement an areawide IPM program that will reduce navel orangeworm damage, aflatoxin contamination, and broad-spectrum insecticide use throughout the Central Valley of California. The NOW-AWPM project is a collaborative effort between ARS scientists, University of California researchers, and farm advisers of the University of California Cooperative Extension Service. By the end of fiscal year 2011, mating disruption, a critical component of this IPM program, had been adopted on 30,000 acres of almonds in the San Joaquin Valley, the southern section of the Central Valley, which is the major almond production region in California. An economic analysis of the cost of almond production conducted as a part of this project concluded that the total cost of production was $3,974 per acre. Insect control accounts for approximately 8.25 percent of this total cost. These calculations will be used to develop a comprehensive program to control this pest using cultural, chemical, and non-chemical approaches. Specific accomplishments for this NOW-AWPM project include:

- ***Changing sanitation guidelines for navel orangeworm in almonds***. The primary non-chemical method used to control navel orangeworm in the Sacramento and San Joaquin Valleys of California is sanitation. ARS scientists, with industry and university collaborators, created an educational interactive spreadsheet emphasizing new standards that is now available on the Almond Board of California Web site. The revised sanitation guidelines will reduce navel orangeworm damage and insecticide use in the multi-billion dollar almond industry.
- ***Phenology of navel orangeworm***. The first flight of navel orangeworm moths in pistachios establishes this pest in the orchard for the rest of the season. ARS researchers determined peak adult emergence using field collected pistachios and compared these peaks to data collected from trapping adults. This information was used to generate emergence curves for the overwintering and subsequent flights of navel orangeworm moths to determine the optimal time for insecticide application, thereby reducing navel orangeworm damage. Data on optimal insecticide timing was presented to growers and pest control advisers in a series of seminars sponsored by the NOW-AWPM project; pistachio growers and the University of California; the University of California Cooperative Extension Service; and industry.
- ***The impact of mating disruption on non-target almond pests and beneficial insects***. It is not known how reduced insecticide use associated with navel orangeworm mating disruption will affect populations of the peach twig borer, oblique-banded leafroller, fruit-tree leafroller, and oriental fruit moth, as well as beneficial insect species in almond orchards in the San Joaquin Valley of California. ARS scientists, with university collaborators, established a 2,000 acre almond demonstration site in the San Joaquin Valley and collected baseline population data on the prevalence of almond pests and beneficial insects. This information will help growers using mating disruption to optimize pest control

and facilitate adoption of this technique. These changes in management practices will decrease both the use of broad spectrum insecticides and damage in this multi-billion dollar almond industry.

Anticipated Product 2B-7: *Enhanced methodologies to capture methyl bromide being used under CUEs or QPS Exemptions.*

ARS personnel with expertise in this area retired in 2009. A new effort on methyl bromide recapture was initiated in January 2011 with a grant from the USDA Foreign Agricultural Service (FAS).

PROBLEM STATEMENT 2C: DEVELOP ALTERNATIVES TO METHYL BROMIDE FOR DISINFESTATION OF POSTHARVEST PERISHABLE COMMODITIES.

Problem Statement: Even though quarantine/preshipment uses of methyl bromide are presently exempted from the provisions of the Montreal Protocol, research is needed to guard against the loss in trade that would result if methyl bromide were lost. Alternative treatments that can be used in place of methyl bromide will include new chemical and non-chemical methods. For perishable commodities such as fresh fruits and vegetables, a number of approaches will be investigated including, radiation treatments, cold, heat, combined heat/controlled atmosphere, and systems approaches. Research to better define the effects of alternative treatments on commodity quality is needed to aid in the development of treatments that do not diminish commodity quality. Systems approaches combine several components to reduce risk of infestation and pest survival to acceptable levels. Research on pest behavior and biology is needed to allow establishment of pest-free zones or reduced-risk zones for species that have demonstrated poor host status or certain pest-commodity combinations such as Caribbean fruit fly infesting citrus and Mexican fruit fly attacking avocadoes. Low prevalence pest zones have been developed using various technologies such as mating disruption and sterile insect release, but further research is needed because the large volume and the biology of their pests have been major barriers to postharvest treatment development.

Research Needs: Alternative fumigants, such as ethanedinitrile and methyl iodide, will be evaluated for efficacy and commodity quality. Pest management application techniques, including system approaches, will be addressed to replace fumigation requirements. Physical methods will be examined, including alterations to temperatures, atmospheric compositions, irradiation, and changes in pressure. All approaches will be evaluated for cost effectiveness.

Outputs:

- A list of the most effective fumigation parameters (time/temperature matrices, dosages, and concentration-times time products) for each promising material for the least susceptible life stage of the targeted species.
- Knowledge of the quality of fumigated commodities using the most effective fumigation.
- Pest monitoring, population suppression by mass trapping and mating disruption, host acceptability, new and more effective methods for pest inspection throughout the system,

physical controls, application of pest-free or low-pest prevalence zone and their combinations, and predictive models along with validation tests of those models.
- New management strategies utilizing sterile insect release technologies and biocontrol with parasitic beneficial insects.
- Additional non-chemical control measures (temperature, pressure, controlled atmospheres, combined treatments, and irradiation) for the least susceptible life stage of the target species, along with the impacts of these techniques on commodity quality.
- Enhanced methodologies to capture methyl bromide used under CUEs or QPS Exemptions.
- Multiple, cost-effective treatments incorporating novel approaches that are safe and provide competitive products in international trade.

PROBLEM STATEMENT 2C: ACCOMPLISHMENT SUMMARY

Research conducted under this Problem Statement seeks to develop effective methods for disinfesting postharvest perishable commodities, such as fresh fruit and vegetables, before marketing domestically and abroad. ARS scientists developed fumigant treatments that meet the requirements of United States' trading partners for controlling pests such as western flower thrips, black widow spiders, and fruit flies; new methods to monitor fruit fly populations including a chemical signature for fruit fly infested grapefruit; new attractants that are efficacious and economical; improved methods to evaluate host status that are accepted internationally; non-chemical commodity treatments including ultra-low oxygen, radiation, and high pressure washing; and an areawide management program for fruit flies in Hawaii that was adopted on 6,383 hectares in 2007, saved $3.5 million, and reduced fruit fly infestations from a level of 30-40 percent to less than 5 percent.

PROBLEM STATEMENT 2C: SELECTED ACCOMPLISHMENTS

Anticipated Product 2C-1: *List of the most effective fumigation parameters (time/temperature matrices, dosages, and concentration-times time products) for each promising material for the least susceptible life stage of the targeted species.*

Western flower thrips control on lettuce and broccoli. ARS scientists demonstrated that pure phosphine fumigation was effective in controlling western flower thrips and safe on lettuce and broccoli. This research provided an immediate solution to western flower thrips control on fresh commodities exported to Taiwan.

Control of black widow spiders in table grapes. Black widow spiders are a problem when grapes are field packed and shipped to European countries. ARS scientists demonstrated that black widow spiders could be killed by 1-hour exposure to 10,000 parts per million of ozone at reduced pressure. This treatment alleviates the reluctance of countries to import U.S. table grapes and increases the demand for this product. After completion of this research, the treatment was applied commercially, on a pilot scale, but it is not currently being used by the table grape industry.

Penetration of methyl bromide through sheets wrapping table grapes imported into the United States. Table grapes, shipped from Chile with wrappers, require an area of perforations in the wrappers equal to 0.9 percent for methyl bromide to penetrate into the grapes. However, that requirement allows sulfur dioxide that is applied to berries to prevent decay, to disperse from around the grapes allowing premature decay of the berries. ARS scientists showed that perforation areas reduced to 0.3 percent allow an adequate penetration of methyl bromide while retaining enough sulfur dioxide to inhibit decay.

Effect of cherry size on methyl bromide fumigation. Exporting cherries to Japan requires methyl bromide fumigation for the commodity to be allowed into the country. Japan sets concentration-by-time product standards for acceptance of cherry imports. ARS scientists determined that neither the concentration by time product achieved nor the sorption of methyl bromide was affected by the size of cherries exposed to the fumigation. As a result of these studies, cherries, regardless of size, have the same fumigation schedule.

New soil drenches for eradication of fruit flies in orchards. One strategy for eradication of fruit flies in orchards is the use of soil drenches under fruit trees. Conventional organophosphorous insecticides, such as diazinon (now banned), have been commonly used this way. However, because of concerns regarding organophosphate effects on human health and wildlife, there is a need for safe and effective drench formulations. ARS scientists have developed laboratory toxicity data for several low toxicity insecticides used as soil controls of Mediterranean, melon, and oriental fruit flies. Studies demonstrated that two commercial pyrethroid insecticides, Warrior® and Force®, are very effective controls for these flies, are similar in toxicity to diazinon, and are as effective as diazinon in controlling these flies. Two other products, Admire® (imidacloprid) and Platinum® (thiamethoxam) also appear promising. Preliminary field trials with Warrior®, Admire®, and Platinum® have indicated that all three of these products should be safe and effective controls for fruit flies in soil.

Anticipated Product 2C-2: *Knowledge of the quality of fumigated commodities using the most effective fumigation.*

Cold temperature fumigation of perishable commodities with phosphine. ARS scientists tested application of phosphine at cold temperature as an alternative to methyl bromide treatment. Initial results showed that the new treatment had no phytotoxic effects on artichokes, white-flesh peaches, or white-flesh nectarines. Further testing revealed that phosphine applied in this manner can damage the exterior of some stone fruit cultivars. Additional experiments are currently underway using different wax formulations and fumigation protocols to resolve this fruit quality issue. Work is also underway to evaluate the effect of this fumigation treatment on other commodities.

Residue remediation using ozone and ozone-ethylene fumigations. Export of California specialty crops can be hampered by the presence of chemical residues that occur as a result of commonly used agricultural practices. ARS researchers evaluated different ways of eliminating these residues while managing insect pests. Fumigation of fruit with ozone, or a combination of ozone and ethylene, was shown to reduce the residue's concentration. This research resulted in a technique, which is applicable to numerous commodity types, for reducing residues to satisfy maximum residue level quotas that serve as trade barriers to California $8 billion specialty crop export.

Anticipated Product 2C-3: *Pest monitoring, population suppression by mass trapping and mating disruption, host acceptability, new and more effective methods for pest inspection throughout the system, physical controls, application of pest-free or low-pest prevalence zone and their combinations, and predictive models along with validation tests of those models.*

Pest Monitoring

Accurate information on the size of pest insect populations, the life stages of members of the populations, and location of the populations is a cornerstone of managing these pests. ARS scientists improved pest monitoring by combining attractants for fruit flies, evaluating detection methods for cherry fruit fly larvae, and determining the range of attraction for capture of medflies and caribflies. ARS scientists also identified signature chemicals for detecting hidden pest infestations, identified infestation sources for three groups of Mexican fruit flies, and found that female Mexican fruit flies are mated before they are attracted to fruit, indicating that the sterile insect technique (SIT) would not be successful with these flies.

- ***Combining attractants for cost-effective fruit fly monitoring traps.*** Fruit flies are among the most economically important pests attacking soft fruits worldwide. For rapid eradication, fruit growers in California and Florida use over 50,000 detection traps containing methyl eugenol for oriental fruit fly, or the man-made raspberry ketone analogue, cue-lure, for melon fly. To reduce the cost of monitoring programs, ARS scientists studied the efficacy of traps containing solid lure dispensers with both methyl eugenol and cue-lure. Captures of oriental fruit flies and melon flies with wafers containing both methyl eugenol and the raspberry ketone (FarmaTech Mallet MC®) were equivalent to those containing separate lures. The use of the FT Mallet MC® wafer with combined lures offers an economical and time-saving approach for the detection of methyl eugenol and cue-lure responding fruit flies and should enhance detection capabilities for these pests.
- ***Evaluation of methods for detecting cherry fruit fly larvae***. Packing houses in the Pacific Northwest use two methods, the brown sugar flotation method and the hot water method, to detect infestations of cherry fruit fly larvae in cherries destined for export. ARS researchers determined that the brown sugar method resulted in a 97 percent detection rate of larvae, whereas the hot water method resulted in an 84 percent detection rate. This provides valuable information to agricultural inspectors on best procedures for assessing the potential infestation of cherry fruit for export.
- ***Determination of effective sampling range of food based attractants for capture of medflies and caribflies***. Sampling range, i.e., the maximum distance from which an insect can reach an attractive source in a given period of time, is an important aspect of trap efficacy. Release/recapture studies using sterile or fertile fruit flies have traditionally been used to determine sampling range. However, due to differences in

nutritional background, the response of these flies to food-based attractants may not be directly applicable to the response of wild flies. ARS conducted studies of field-collected Mediterranean fruit flies in Honduras and Caribbean fruit flies in south Florida to test a geostatistical approach that used high density trapping grids to estimate sampling range of the standard food-based synthetic attractants for these flies. These estimates were compared with those obtained from release/recapture studies. Effective sampling range for three component and two component food-based lures was found to be 30 meters for both fruit fly species. These results have been applied by action agencies to trapping protocols in eradication efforts for new invasions of medflies, such as the outbreaks in south Florida.

- ***Signature chemicals for detection of hidden insect infestation***. Quarantine inspectors at U.S. ports visually check produce shipments by manually cutting open a small sample (typically 2 percent or less) of fruit to search for infestation. Studies were conducted to determine if gas chromatography could be used to improve the detection of hidden pest infestations. ARS scientists found that grapefruit infested with the Caribbean fruit fly larvae emitted a chemical profile distinct from that of non-infested fruit, providing a “signature” that can be used for rapid, reliable screening protocols. This technology has been transferred and is undergoing beta testing by APHIS for use incorporation into plant inspection protocols.
- ***Infestation sources can help identify the pathway of invasive fruit flies***. Infestation by invasive fruit fly species occurs on a semi-regular basis in the fruit production areas of the United States. Population genetic studies could help identify the origin of these infestations if regional populations can be differentiated. Analysis of data by ARS scientists, in collaboration with APHIS, found that there are three genotypes of Mexican fruit fly, a dominant form in Mexico and two minor forms in Central America, one occurring only in Costa Rica. Similarly, there are two forms of West Indian fruit fly (a pest of mangos) in the same area, one in western Mexico and one in eastern Mexico and Central America. Knowledge of the source of an infestation can help identify the pathway by which an invasive species was introduced and steps could be taken to close off the pathway or develop mitigative steps for commodities in that pathway.
- ***Phenomena between weather patterns and fruiting on pest populations of the Mexican fruit fly***. Mexican fruit fly (Mexflies) infestations occur sporadically in the United States, invoking quarantines and disrupting markets. ARS scientists determined that fruit fly population peaks are tied to the springtime fruiting sequence, which in turn is dependent on weather conditions, especially rainfall patterns. ARS researchers conducted a study that showed gravid female Mexflies are attracted to, and thus move into, native fruit-bearing host trees in their natural habitat in the mountains of Mexico. If females are already mated before they are attracted to fruit, these females would not be susceptible to the SIT, which is the primary method for protecting groves in the United States. As a result of this information, the IPM program for Texas citrus crops now integrates traditional bait sprays with the SIT. A prophylactic spray is applied to a grove where a single wild Mexfly is detected, rather than relying on the SIT alone and waiting for a population peak to apply controls, which is the more traditional approach.

Lures, Attractants, and Baits

Lures and attractants facilitate pest monitoring for quarantine or pest control. ARS scientists developed a new, female-based attractant for the melon fly, a synthetic lure combination for fruit flies, a fruit-derived bait station for fruit flies, and a spinosad attractant combined with an insecticide for control of oriental fruit fly. ARS scientists also developed a fruit-derived bait to kill fruit flies and identified cadaverine for attracting tephritid fruit flies.

- ***New female attractant for melon fly.*** Female-biased attractants are important components of many effective insect detection suppression traps, such as those used for monitoring and controlling fruit flies. ARS scientists have developed a female-biased attractant for melon fly, which can be used for detection of the melon fly. This new attractant can detect, and in some cases control, melon fly populations when combined with other suppression techniques.
- ***Synthetic lure combinations show improvement.*** Exotic species of fruit flies, such as medfly, Mexfly, West Indian fruit fly, and sapote fruit fly, are invasive pests that trigger quarantines and eradication programs when found in the United States. Baited traps have been effective surveillance tools, but improved trap designs and more attractive lures are needed in order to maintain this early warning system. ARS scientists tested new lures and lure combinations in Mexico against wild populations of Mexican, West Indian, and sapote fruit flies and found that the release rate was as important as the blend of components in a lure. While different fly species respond differently to the blends, a simple three-component lure may be efficacious, if not optimal, against an array of exotic species, reducing the manpower needed to operate separate traps for each target pest.
- ***Cadaverine in a food based synthetic attractant for pest tephritid fruit flies.*** Putrescine, which is used in combination with ammonium acetate in traps for attracting pest fruit flies, is difficult to analyze chemically, and the attraction of fruit flies to this compound may be due to impurities in the formulation. ARS scientists determined the response of the Caribbean fruit fly to a series of homologous terminal diamines, with electroantennography and field tests. Cadaverine elicited both electroantennography and behavioral responses comparable to that of putrescine. The use of cadaverine as an alternative to putrescine is under consideration by action agencies to detect new invasions of pest fruit flies that threaten U.S. agriculture.
- ***Bait station and fruit-derived bait testing in central Mexico.*** A station that attracts and kills pestiferous fruit flies and thereby protects fruit from infestation has been developed and tested with sterile flies in Texas, and with low populations of fruit fly pests in northern Mexico. Although grapes are not considered an important host for fruit flies, ARS scientists determined that commercial grape juices and juice concentrates were superior to the protein hydrolysate baits used for fruit fly monitoring and captured 2 to 10 times more flies per trap. To test the functions of these baits for fruit fly suppression, baits were tested in stations in San Luis Potosi, Mexico, and in small isolated orchards. Pest suppression using the bait in a station was equivalent to weekly pesticide sprays. This research provides data showing that

the bait stations with effective attractant baits have potential to control fruit fly populations at a level comparable to pesticide bait sprays.

- ***Spinosad replacement for organophosphate male annihilation treatments in California.*** Naled is used as the toxicant in traps baited with methyl eugenol for oriental fruit fly control. ARS scientists conducted studies to quantify attraction and feeding response resulting in mortality of the male oriental fruit fly to traps containing spinosad instead of naled. Results suggest that spinosad plus a pheromone, insect lure, and methyl eugenol offers a reduced risk alternative for control of oriental fruit fly, without many of the negative effects to humans and non-target organisms that are common with broad spectrum contact poisons such as naled. This research offers potential for control of males in an areawide IPM system without the need for conventional organophosphates.

Host Status

Specific knowledge of plant hosts that are used, and those preferred, at different stages in the insect life cycle is needed for quarantine and pest management. ARS scientists discovered where the West Indian fruit fly lays eggs on grapefruit and that Texas grapefruit is a poor host for this insect, but a good host for the Mexican fruit fly. Scientists also determined that the Mexican fruit fly survives well on grapefruit and orange, while the serpentine fruit fly does not. ARS scientists provided host information to APHIS for establishing international standards for host lists and experimental determination of host status.

- ***Improved methods for evaluating non-host status of horticultural crops for fruit flies***. The United States requires that quarantine treatments for high risk pests, such as fruit flies, achieve 99.9968 percent (probit-9) mortality at the 95 percent confidence level by treating a minimum of 93,613 insects, with no survivors. This is the standard for an acceptable level of risk for introduction of high risk pests. ARS scientists proposed that the same level of testing be required to document non-host status of fruits and vegetables for specific fruit flies. This will result in an equivalent standard for risk whether through postharvest treatments or host status. Sample size would be determined by the number of insects exposed to fruit or the number of fruit collected to inspect for insects. This recommendation was included in a new North America Plant Protection Organization (NAPPO) Regional Standard for Phytosanitary Measures, which provides guidelines for determination of host status of a commodity to fruit flies (RSPM No. 30). Incorporating sample size and confidence levels into host status testing protocols, along with efficacy, will lead to greater consistency by regulatory decision-makers in interpreting results and, therefore, more technically sound decisions on host status.

- ***New approaches to host status evaluation***. ARS scientists evaluated grapefruit as a host for *Anastrepha obliqua*, the West Indian fruit fly, by utilizing analysis of life tables to evaluate survival of eggs and larvae of the fly in the peel and pulp tissues. Results showed that egg mortality due to inability of the females to oviposit below the oil glands and most larval mortality occurred in the albedo (white part) tissue of the peel. Larvae that burrowed into the pulp had high rates of survival to the pupal and adults stages. Results from the West Indian and the Mexican fruit fly showed that in

Texas, grapefruit are very poor hosts before February 15th, with eggs and larvae having nearly 100 percent mortality, but after April 1st Mexican fruit fly readily utilizes the fruit.

- ***Host status of grapefruit and oranges for the serpentine fruit fly.*** The serpentine fruit fly, *Anastrepha serpentina*, apparently spread north from central Mexico during the late 1920's and early 1930's and was the most common pestiferous fruit fly trapped in Texas orchards during the late 1930's. The species has largely disappeared from Texas but occasional captures result in the imposition of quarantines and require eradication. Only one report in Texas of serpentine fruit fly larvae in grapefruit was found during a period of high fly population (1930's). ARS scientists compared serpentine fruit flies with the Mexican fruit fly, a known pest of citrus. Eggs of the serpentine fruit fly hatched at about 10 percent the rate of the Mexican fruit fly rate in grapefruit and oranges. Larval mortality in the albedo (white part) of the peel was 100 percent for serpentine larvae in oranges and greater than 95 percent in grapefruit, compared to about 60 percent mortality for Mexican fruit fly larvae in these fruit. However, if larvae of either species entered the pulp in grapefruit, adults could emerge. The much lower rate of survival of eggs and larvae of the serpentine fruit fly as compared to the Mexican fruit fly indicates that serpentine fruit fly captures in grapefruit and orange production areas are less likely to be a significant pest.
- ***Tropical fruit fly host status***. The potential and actual breeding hosts for tropical fruit flies determine the need for quarantine actions in both international and domestic trade. Currently, there are no international standards for correcting host lists or determining host status. ARS researchers reviewed factors contributing to host specificity and host selection by fruit flies and compiled the available information into a chapter for the Annual Review of Entomology. This review served as a guideline for studies of citrus (oranges, grapefruit), and native *Sapotaceae*. The Annual Review of Entomology also served as a guideline for reviews of experiments by trading partners, to derive a standard method for examining resistance factors and how they affect infestation of commercial and wild fruit. An experimental procedure with a supporting example for determining resistance factors was completed and a summary was presented to the APHIS Plant Protection and Quarantine (PPQ) and International Services to establish international standards for host lists and experimental determination of host status.

Anticipated Product 2C-4: *New management strategies utilizing sterile insect release technologies and biocontrol with parasitic beneficial insects.*

Biological control of olive fruit fly. Economical methods are needed to control olive fruit fly in California to protect the U.S. domestic supply of canned olives and olive oil. A parasitoid was produced in mass numbers in the APHIS PPQ Moscamed facilities in Guatemala and shipped to California for release by ARS scientists in areas infested with olive fruit fly. Laboratory and field tests showed that the parasitoid reduced numbers of olive fruit fly during the olive growing season. Development of biological control methods for olive fruit fly supports the California olive industry, which is valued at $75 million annually.

Augmentative releases of multiple natural enemies for melon fly control. Wild melon species can function as hosts for melon fly, which can exacerbate melon fruit fly control in nearby vegetable farms. Controlling melon fly on wild melon species with pesticides can be logistically difficult and economically prohibitive. To address these problems, ARS scientists evaluated the use of the fruit fly parasitoids *Fopius arisanus* (Sonan) and *Psyttalia fletcheri* (Silvestri) for suppression of melon fly infestation of wild ivy gourd growing near small vegetable farms. Concurrent releases of both parasitoids suppressed melon fly populations, with a concomitant reduction in the melon fly population in nearby vegetable farms. These field studies confirmed previous laboratory evaluations and will be of value in developing a non-pesticide strategy for controlling melon fruit flies in non-crop and crop lands; a strategy that could be incorporated into an IPM program for melon fly in Hawaii, and similar climates around the world where such infestations occur.

New genes for lethality in fruit flies. Mass releases of sterile males are widely used to control pest fruit flies, but the radiation that sterilizes males often damages their sexual performance. Conditional lethality, where a released insect's offspring die when certain environmental conditions prevail, is a promising substitute for traditional sterility. Several new genes critical for conditional embryonic lethality have been discovered by ARS researchers in the Mexican and Caribbean fruit flies, and these could ultimately improve the efficacy of control programs that protect U.S. agriculture from fruit flies and other potentially invasive pests.

Anticipated Product 2C-5: *Additional non-chemical control measures (temperature, pressure, controlled atmospheres, combined treatments, and irradiation) for the least susceptible life stage of the target species, along with the impacts of these techniques on commodity quality.*

Cold treatment for Bactrocera invadens adopted by APHIS. ARS developed the first cold treatment for *Bactrocera invadens*, a new invasive fruit fly that threatens world trade and production of many fruit crops, which has been accepted by APHIS and is included in the APHIS Treatment Manual.

Heat exposure threshold to maintain flavor quality of navel oranges. ARS researchers determined that 150 minutes at 45°C was the upper limit of heat exposure that did not adversely affect orange fruit flavor. Knowledge of this flavor quality threshold will be used in developing heat application as a treatment for controlling insect pests in navel oranges.

Ultra-low oxygen treatment for control of postharvest pests. Presence of postharvest pests on U.S. fresh commodities can be a major obstacle to exportation, pose safety hazards to workers as well as consumers, or spread pests that are also vectors of significant pathogens. With short treatment time, low temperature, and easily attainable oxygen level, ultra-low oxygen treatments have good commercial potential.

- ***Black widow spiders in table grapes***. ARS scientists found that 1-day exposure to atmospheres with 0.5 percent O_2 or lower, at low temperature, was adequate for successful control of the spiders and did not affect grape quality.

- ***Western flower thrips on lettuce***. In a pallet-scale study, ARS researchers determined that a 3-day storage period immediately prior to ultra-low oxygen treatment achieved complete control of thrips without any negative effects on lettuce quality.

Controlled Atmosphere Temperature Treatment System (CATTS). A non-chemical, quarantine treatment system was developed and demonstrated to be effective in controlling codling moth, oriental fruit moth, and western cherry fruit fly in apples, peaches, nectarines, and sweet cherries. These treatments effectively control the most tolerant stage of all these species, while maintaining fruit market quality. CATTS treatments for apples, peaches, nectarines, and sweet cherries have been included in the APHIS Plant Protection and Quarantine (PPQ) Treatment Manual.

- ***Codling moth metabolism.*** ARS scientists determined that low oxygen environments inhibited the ability of codling moth to respond to increasing temperatures and high levels of carbon dioxide blocked the insect's ability to utilize ATP for energy. The combination of low oxygen and high carbon dioxide worked synergistically to inhibit codling moth from metabolically adapting to the high temperatures.
- ***Oriental fruit moth in boxed peaches.*** ARS researchers determined that a combination treatment of forced air heat and controlled atmosphere applied to commercial pallets of peaches infested with oriental fruit moth resulted in 100 percent mortality of this insect pest. A variety of box configurations and venting options were tested and researchers found that a commercial single layer box with side venting provided the fastest and most uniform heating. Actual commercial viability of the treatment is unclear, given the difficulty in ensuring that individual boxes are heated equally within numerous stacked pallets of fruit.
- ***Oblique-banded leafroller and peach moth***. ARS scientists determined that the immature stages of the oblique-banded leafroller and the peach fruit moth were less tolerant to combinations of heat and controlled atmosphere treatments than codling moth and oriental fruit moth. The fifth instar of oblique-banded leafroller and the last instar of the peach fruit moth were determined to be the most tolerant stages to short term high temperatures in combination with controlled atmospheres. These results show that currently available treatments for codling moth and oriental fruit moth can also be used for oblique-banded leafroller and peach moth.
- ***Grain chinch bug (Macchiademus diplopterus) and snout beetle (Phlyctinus callosus).*** ARS scientists, in collaboration with university scientists in South Africa, determined that treatment of both species was more effective under two heating rates when the controlled atmosphere condition was also applied. Under controlled atmospheres, mortality of *Phlyctinus callosus* was greater when the faster heating rate was used, while the opposite was true for *Macchiademus. diplopterus*. This could be due to the physiological condition of aestivation (characterized by a low metabolic rate and inactivity), which contributes to metabolic arrest, in response to the stresses being applied during treatment.

Radiation. Irradiation can be an important alternative to fumigation with methyl bromide for quarantine pest control when it is effective and does not cause unacceptable phytotoxic effects.

- ***Potential increase in live fruit fly larval interceptions using radiation treatments*.** ARS scientists found that although fruit fly eggs and larvae are not rapidly killed with radiation and therefore might still be alive during inspection, they die before reaching the adult stage and therefore do not pose a risk of invasion.
- ***Quarantine treatment against scale insects.*** ARS scientists developed the first quarantine irradiation treatments for two diaspidid scale insects when they showed that an irradiation dose of 150 Gy is sufficient to provide quarantine security for coconut scale and white peach scale, high-risk quarantine pests of banana and papaya respectively. The research on white peach scale provided the information needed to lower the required papaya irradiation treatment of 400 Gy to 150 Gy, which will significantly reduce treatment costs and the likelihood of fruit damage. Approximately 5 million pounds of papayas are exported annually from Hawaii to the Continental United States using radiation as a treatment.
- ***Dragon fruit shown to be tolerant of irradiation quarantine treatment.*** Dragon fruit is a host of fruit flies that are subject to quarantine restrictions when shipped from Hawaii to the Continental United States. ARS scientists established that irradiation treatment of dragon fruit at doses of 400- 800 Gy would ensure visual and compositional quality, while providing quarantine security against fruit flies and other insect pests. This new treatment will support an expansion of high value specialty fruit exports from Hawaii, with subsequent benefit to Hawaiian agriculture.
- ***Ionizing radiation as a phytosanitary treatment against the European corn borer***. ARS scientists determined that the minimum absorbed dose for phytosanitary irradiation against the European corn borer, a quarantine pest for several fresh commodities grown in the eastern United States, was 233 Gy. This treatment was not affected by temperature, but was made less efficacious in the presence of low oxygen.

High pressure washing and organosilicones for removal of surface arthropods. ARS scientists demonstrated that high pressure washing alone or in combination with organosilicones, like Silwet, were effective in removing surface arthropods, like spider mites, mealybugs, and eggs of Lepidopteran pests on apples and winter pears. ARS researchers also demonstrated that the addition of a heated contact loop in the recirculated water of the high pressure wash system reduced the numbers of decay organisms, like molds, which improved the quality of the fruit in storage.

Fate of codling moth in apples exported to tropical climates. ARS scientists completed a study of codling moth in apples that are exported to countries below the 30^{th} latitudes. ARS researchers found that codling moth cannot successfully complete diapause and establish a population in climates that do not have at least 30 consecutive days below

10°C and a day length of more than 15 hours. Based on over 10 years of export and inspection data on apples exported to Taiwan from the Pacific Northwest, ARS scientists calculated that less than 1 percent of codling moths would emerge each year under the environmental conditions in Taiwan. These data can be used by regulatory agencies for use in risk analyses.

Anticipated Product 2C-6: *Enhanced methodologies to capture methyl bromide used under CUEs or QPS Exemptions.*

ARS expertise in this area retired in 2009. A new effort on methyl bromide re-capture was initiated in January 2011 with a grant from the FAS.

Anticipated Product 2C-7: *Multiple, cost-effective treatments incorporating novel approaches that are safe and provide competitive products in international trade.*

Phytosanitary treatments are adopted by the International Plant Protection Convention. The International Plant Protection Convention has begun developing a treatment manual for international harmonization of phytosanitary measures. This will aid the United States and other countries in the trade of quarantined commodities. Eleven treatments have been adopted so far, and seven of these were developed, wholly or in large part by ARS scientists, showing considerable international confidence in this research.

Pure phosphine fumigation at low temperature for control of western flower thrips on lettuce, broccoli, asparagus, and strawberries. Produce exported to Taiwan often harbors western flower thrips, a quarantined pest. ARS scientists, in collaboration with industry, demonstrated pure phosphine fumigation in a reefer container to be effective in controlling western flower thrips and safe on all of the commodities tested in a commercial-scale fumigation trial, i.e., lettuce, broccoli, asparagus, and strawberries. This would provide an effective solution to western flower thrips control on exported fresh commodities to Taiwan; however, its commercial use is hindered by the lack of low temperature fumigation infrastructure. ARS researchers then developed and demonstrated to be safe and effective in semi-commercial pallet scale tests, a method of fumigating pre-chilled lettuce under an insulation cover. This new method provided an economical alternative to fixed, low temperature fumigation chambers for conducting low temperature phosphine fumigation for control of western flower thrips on lettuce and has the potential to be used for control of other phosphine-susceptible insects.

Low temperature oxygenated phosphine fumigation for controlling lettuce aphid. ARS researchers found that oxygen significantly increases phosphine toxicity against lettuce aphid. At low temperatures, phosphine fumigation under 60 percent oxygen reduced treatment time from 3 days to 30 hours. The shorter oxygenated phosphine fumigation controlled lettuce aphid in a pallet-scale trial with chilled head lettuce under an insulation cover. The treatment was safe to lettuce quality, achieved complete control of the insect, and provided an economical alternative to fixed low temperature fumigation chambers for conducting low temperature phosphine fumigation.

Insecticide mix prevents egg laying by cherry fruit fly. Cherry fruit fly is a major quarantine pest of cherries, as there is a zero tolerance for larvae in marketed fruit. Insecticide sprays are targeted against the young flies before they develop and can lay eggs. However, flies that are mature and capable of laying eggs can fly into orchards and infest cherries even after contacting the insecticide sprays currently being used, indicating more effective materials are needed to keep these flies from laying eggs. ARS scientists found that, when ingested, a mix of spinosad and the neonicotinoid thiamethoxam can prevent flies from laying eggs into cherries, whereas the current material used, spinosad bait, cannot. The use of a spinosad and thiamethoxam mix can reduce the problem of unsprayed cherry flies moving into orchards from outside sources and can be part of a systems approach for export of cherries.

Precision management of codling moth. Codling moth, a major pest of apple and pear, is primarily managed with a series of calendar sprays applied to the entire orchard. To reduce costs, as well as the potential negative impacts to human health and the environment, ARS scientists tested the use of precision agriculture techniques that restrict pesticide applications, both spatially and temporally. Insect traps baited with lures attractive to both sexes of the moth were distributed in high density across several hundred acres of pear trees, and only the portions of the field where male and female moths were detected above a set threshold were sprayed. Management costs for codling moth were reduced 40 to 60 percent, which also reflects a significant decrease in pesticide exposure for applicators and the environment. Adoption of this precision agriculture approach for codling moth, in both pear and apples, could reduce both the acreage treated and the management costs throughout the fruit growing regions of the western United States.

Data to WTO for expansion of apple exports. Because fire blight disease occurs in the United States but not in Japan, Japan restricted the import of U.S. apples for decades even though there was no scientific evidence showing that apple fruit could spread the disease. Although the United States won a WTO dispute against Japan over the issue in 2005, Australia was taken to the WTO in 2009 over the same issue, because it maintains similarly restrictive import regulations that prevent the export of U.S. and New Zealand apples to Australia. Because both WTO cases were based, in large part, upon fire blight research done by ARS scientists, ARS provided technical support to APHIS, the counsel for the office of the U.S. Trade Representative, and the New Zealand Ministry of Agriculture, Forestry and Fisheries, by providing technical review and comment on both of New Zealand's submissions (first, rebuttal, and then answers to panel questions) and the third-party submission of the United States. Both the New Zealand first-party submission and the U.S. third-party submission relied heavily upon a revised risk assessment published in 2008 by ARS scientists, which estimated the risk of importing the fire blight bacterium *Erwinia amylovora* on commercial apple fruit. This risk was found to be negligible, and this document was used by both the United States and New Zealand to argue their respective cases against the fire blight import regulations proposed by Australia for U.S. and New Zealand apples. The WTO Panel ruled in favor of New Zealand, heard the appeal to the ruling and decided again in favor of New Zealand. This outcome should provide leverage to help open the Australian and other markets to U.S. apples.

Areawide Pest Management of Fruit Flies in Hawaii. In 1999, ARS initiated the Areawide Pest Management of Fruit Flies in Hawaii-Areawide Pest Management (FF-AWPM) project to develop an IPM program to suppress fruit flies below economic thresholds, reduce the use of organophosphate insecticides, and promote the expansion of diversified agriculture. This project was conducted in cooperation with the University of Hawaii, the Hawaii Department of Agriculture, industry, and growers. The FF-AWPM project secured special local needs registrations for agricultural chemicals; implemented a fruit fly IPM extension educational program; developed site specific implementation plans; and initiated trapping, sanitation, and control measures within defined areas on Hawaii, Maui, and Oahu Islands. By the end of fiscal year 2007 the IPM program had been adopted by 2,540 cooperators on over 607 farms encompassing 6,383 hectares throughout the state. An economic analyst estimated the industry benefit of the IPM program to be $3.5 million in 2007 and the internal rate of return to be 28 percent. Using methods of the IPM program rather than conventional chemical pesticides, growers reduced fruit fly infestation from 30 to 40 percent to less than 5 percent. California and Florida have also shown a keen interest in the project. California alone would suffer a $1.4 billion annual loss in export sanctions, treatment costs, lost markets and reduced crop yields if the medfly becomes established. Specific accomplishments for the FF-AWPM project include:

- ***Registration of key control for fruit flies***. Organophosphates used as toxicants in insect traps for fruit flies insecticides have been phased out of use because of their negative effects on human health and wildlife. In June 2008, through an ARS and industry partnership, ARS scientists in Hilo, Hawaii, registered SPLAT-MAT™-Spinosad-ME, an effective insect trap with spinosad, a natural insecticide with low human toxicity and little effect on beneficial insects. In 2010, this product was licensed for use in Hawaii and California and is projected to have worldwide application for fruit fly eradication.
- ***Suppression of fruit fly in papaya orchards using bait sprays and field sanitation***. A major goal of the FF-AWPM project was to suppress fruit flies below economic thresholds while integrating biologically-based pest technology into a comprehensive management package that is economically viable, environmentally sensitive, and sustainable. Two major technologies tested by ARS scientists included field sanitation and spinosad protein bait sprays. Since oriental fruit fly has proven to be among the most difficult fruit fly species to control, the efficacy of FG-120 Naturalyte Fruit Fly Bait in combination with field sanitation was assessed as a control for female oriental fruit fly in papaya orchards. Results suggested that foliar applications of GF-120 NF Naturalyte Fruit Fly Bait, either to all rows (every other tree), or to every fifth row (every tree), in combination with good sanitation, effectively reduces oriental fruit fly infestation in papaya orchards, while parasitism rates by fruit fly natural enemies were not affected. Reduced fruit fly infestations allows delaying harvest beyond

the mature green or color break stage, which is done to prevent infestations, resulting in increased fruit quality and higher profits.

- ***Soil drenches to control fruit flies.*** The banning of diazinon has resulted in the loss of an effective insecticide in soil drenches for the control of fruit flies. ARS scientists found that two pyrethroid insecticides, Warrior® and Force®, are very effective as soil controls of three fruit fly species; Mediterranean fruit fly, melon fly, and oriental fruit fly. Two other products, Admire® (imidacloprid) and Platinum® (thiamethoxam) also appear promising. Preliminary field trials with Warrior®, Admire®, and Platinum® have indicated that all three of these products should be effective controls for fruit flies in soil.

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Appendix I

National Program 308: Methyl Bromide Alternatives
ACCOMPLISHMENT REPORT 2006-2011

Relationship of National Program 308 to the ARS Strategic Plan

Outputs of NP 308 research support the actionable strategies that are associated with the performance measure shown below from the ARS Strategic Plan for 2006-2011. This performance measure falls under Strategic Goal 4: Enhance Protection and Safety of the Nation's Agriculture and Food Supply; Objective 4.2: Reduce the Number, Severity, and Distribution of Agricultural Pest and Disease Outbreaks.

> **Performance Measure 4.2.3**: Develop control strategies based on fundamental and applied research to reduce losses caused by plant diseases, nematodes, arthropods, and weeds that are effective and affordable, while maintaining environmental quality. Develop technically and economically feasible alternatives to preplant and postharvest use of methyl bromide.
>
> **Target:** Specific information and technology, using methods cited above, will be made available to producers and the research community to exclude, control, and/or better manage disease and pest outbreaks as they occur. Strategies and approaches will be made available to producers to identify and control, and/or effectively manage, over 10 new and emerging crop diseases and pests.

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Appendix II

National Program 308: Methyl Bromide Alternatives
ACCOMPLISHMENT REPORT 2006-2011

Research Projects

ARS Project Number*	Title	Problem Area(s) Addressing	PI	Location
0500-00044-020-00D	South Atlantic Areawide Pest Management Project for methyl bromide alternatives	Preplant: 1B and 1D	Daniel O. Chellemi	Fort Pierce, Florida
0500-00044-021-00D	An ARS Areawide Pest Management Program for methyl bromide alternatives	Preplant: 1D	Greg T. Browne	Davis, California
1230-22000-029-00D	Biologically-based management strategies for control of soil-borne pathogens…an alternative to methyl bromide pre-plant soil fumigation	Preplant: 1A and 1C	Dilip K. Lakshman	Washington, D.C.
1265-21220-178-00D	Integration of biologically based technologies for suppression of soilborne plant pathogens	Preplant: 1A and 1C	Daniel P. Roberts	Beltsville, Maryland
5302-13220-004-00D	Alternatives to methyl bromide for California cropping systems	Preplant: 1A and 1B	Dong Wang	Parlier, California
5305-22000-012-00D	Control of pathogens in strawberry and vegetable production systems	Preplant: 1A and 1C	Frank N. Martin	Salinas, California
5350-22000-017-00D	Biologically-based systems for soilborne disease control in tree fruit agro-ecosystems	Preplant: 1A and 1C	Mark Mazzola	Wenatchee, Washington

ARS Project Number*	Title	Problem Area (s) Addressing	PI	Location
6618-22000-035-00D	Vegetable grafting for resistance to soil-borne diseases	Preplant: 1A	Michael Bausher	Fort Pierce, Florida
6618-22000-036-00D	Alternatives to methyl bromide soil fumigation for vegetable and floriculture production	Preplant: 1A and 1B	Daniel O. Chellemi	Fort Pierce, Florida
5302-43000-033-00D	New chemically based methods which reduce the use or emissions of chemicals as alternative to methyl bromide for quarantine and post-harvest pests	Postharvest: 2A, 2B, and 2C	David M. Obenland	Parlier, California
5302-43000-034-00D	Biological, behavioral, and physical control as alternatives for stored product quarantine of fresh/dried fruits and nuts	Postharvest: 2B and 2C	J.A. Johnson	Parlier, California
5305-43000-003-00D	Post-harvest pest control on perishable agricultural commodities using controlled atmospheres and pure phosphine treatments	Postharvest: 2C	Yong Biao Liu	Salinas, California
5430-43000-028-00D	Development of integrated pest management programs to reduce methyl bromide fumigations for control of insects in post-harvest structures	Postharvest: 2A and 2B	James Campbell	Manhattan, Kansas
6204-43000-015-00D	Development of quarantine alternatives for subtropical fruit and vegetable pests	Postharvest: 2C	Robert L. Mangan	Weslaco, Texas
6615-22430-003-00D	Development of integrated pest management programs to reduce methyl bromide fumigations for control of insects in post-harvest structures	Postharvest: 2A	Richard T. Arbogast	Gainesville, Florida
6631-22000-004-00D	Protection of subtropical and tropical agriculture commodities and ornamentals from exotic insects	Postharvest: 2B and 2C	Nancy D. Epsky	Miami, Florida

*NP 308 research projects are referred to by their ARS project numbers, which are used to track research projects in the agency's internal database.

Appendix III

National Program 308: Methyl Bromide Alternatives Accomplishment Report 2006-2011

Publications by Component

Research Component 1: Preplant Soil Fumigation Alternatives

2011

Browne, G.T., Grant, J.A., Schmidt, L.S., Leslie, C.A., McGranahan, G.H. 2011. Resistance to *Phytophthora* and graft compatibility with Persian walnut among selections of Chinese wingnut. HortScience. 46:371-376.

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Weiland, G.E. 2011. Influence of isolation method on recovery of *Pythium* species from forest nursery soils in Oregon and Washington. Plant Disease. 95:547-553.

2010

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Bull, C.T., De Boer, S., Denny, T., Firrao, G., Saux, M., Saddler, G., Scortichini, M., Stead, D.E., Takikawa, Y., Young, J.M. 2010. Comprehensive list of names of plant pathogenic bacteria, 1980-2007. Journal of Plant Pathology. 92:551-592.

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Kokalis-Burelle, N., Rosskopf, E.N., Hartman, R.D. 2010. Evaluation of soil treatments for control of *Meloidogyne arenaria* in *Caladium* tubers (*Caladium x hortulanum*) and nematode susceptibility of selected cultivars. Nematropica. 40:177-189.

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2007 Publications, Component 2 [continued]

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Appendix IV

National Program 308: Methyl Bromide Alternatives
ACCOMPLISHMENT REPORT 2006-2011

Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions

Results of the most recent research on methyl bromide alternatives are often found in the "Proceedings of the Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions." As the papers explaining these results have not been peer-reviewed, they are not included in Appendix III, Publications by Component. Following are links to each year's conference homepage and conference program, which in turn link to a .PDF of each presentation/paper.

2006
Program: http://www.mbao.org/2006/0006-06ConfProgram.doc
Proceedings: http://www.mbao.org/2006/06Proceedings/mbrpro06.html

2007
Program: http://www.mbao.org/2007/0006-07ConfProgram.doc
Proceedings: http://www.mbao.org/2007/Proceedings/mbrpro07.html

2008
Program: http://www.mbao.org/2008/0006-08ConfProgram.pdf
Proceedings: http://www.mbao.org/2008/Proceedings/mbrpro08.html

2009
Program: http://www.mbao.org/2009/0006-09ConfProgram.doc
Proceedings:
http://www.mbao.org/2009/Proceedings/Methyl%20Bromide%20Phaseout%20--%20Proceedings%20of%202009%20Alternatives%20Research%20Conference.htm

2010
Program: http://www.mbao.org/2010/0006-10ConfProgram.doc
Proceedings:
http://www.mbao.org/2010/Proceedings/Methyl%20Bromide%20Phaseout%20--%20Proceedings%20of%202010%20Alternatives%20Research%20Conference.htm

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Appendix V

National Program 308: Methyl Bromide Alternatives
ACCOMPLISHMENT REPORT 2006-2011

Inventions and Patents

Four patents were issued for years 2006 through 2011 (to date).

Title of Invention:
Ultra-low Oxygen Treatment for Postharvest Pest Control on Agricultural Products
This invention was issued a patent on August 3, 2010.

Title of Invention:
Navel Orangeworm Pheromone Composition
This invention was issued a patent on February 2, 2010 and has been licensed exclusively.

Title of Invention:
Under Bed Fumigator
This invention was issued a patent on December 19, 2007.

Title of Invention:
Under Bed Fumigator
This invention was issued a patent on April 3, 2007.

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Appendix VI

National Program 308: Methyl Bromide Alternatives
Accomplishment Report 2006-2011

Customer Workshops and Meetings

Methyl Bromide Alternatives Assessment and Customer Workshops

- February 1–2, 2006, Orlando, Florida
- February 28–March 2, 2006, Monterey, California

Areawide Pest Management (AWPM) Projects

- AWPM Project to Control Navel Orangeworm in Almonds, Pistachios, and Walnuts
    - August 17–19, 2010, Redley, California
    - Spring 2009, Parlier, California
    - Spring 2008, Parlier, California
    - Spring 2007, Parlier, California
- AWPM Project for Methyl Bromide Alternatives
    - Pacific West Methyl Bromide Core Executive Team Meetings (customers/stakeholders)
        - April 5, 2011, San Joaquin Valley Agricultural Sciences Center, ARS, USDA, Parlier, California
        - February 15–19, 2010, Salinas, California and San Joaquin Valley Agricultural Sciences Center, ARS, USDA, Parlier, California
        - February 5, 2009, San Joaquin Valley Agricultural Sciences Center, ARS, USDA, Parlier, California
        - April 1, 2008, San Joaquin Valley Agricultural Sciences Center, ARS, USDA, Parlier, California
        - April 16, 2007, San Joaquin Valley Agricultural Sciences Center, ARS, USDA, Parlier, California
        - August 8, 2006, San Joaquin Valley Agricultural Sciences Center, ARS, USDA, Parlier, California
    - South Atlantic Core Executive Team Meetings (customers/stakeholders)
        - December 7–8, 2010, Maitland, Florida
        - May 18–19, 2010, Maitland, Florida
        - October 6–7, 2009, Orlando, Florida
        - November 8, 2006, Orlando, Florida
    - Stakeholder meeting with California strawberry industry, June 21, 2006, Watsonville, California
    - Results and discussion meeting with stakeholders, September 5, 2008, University of California, Davis, California

  - Outreach subcommittee meeting, December 7, 2010, Almond Board of California headquarters, Modesto, California

Program and Location Reviews, with Customers/Stakeholders

- February 13–16, 2011, Parlier, California, Location Review
- October 20-23, 2008, Expert Review of Research Units (3 of 5 units), ARS Center for Grain and Animal Health Research, Manhattan, Kansas

Other Workshops and Meetings

- Annual International Research Conference on Methyl Bromide Alternatives and Emissions Reductions (MBAO), http://mbao.org
  - November 2–5, 2010, Orlando, Florida
  - November 10–13, 2009, San Diego California
  - November 11–14, 2008, Orlando, Florida
  - October 29–November 1, 2007, San Diego California
  - November 6–9, 2006, Orlando, Florida
- Methyl Bromide Technical Options Committee Meetings (MBTOC)
  - March 2011, Antalya, Turkey
  - November 2010, Bangkok, Thailand
  - September 2010, San Jose, California (Preplant)
  - September 2010, Zagreb, Croatia (Postharvest)
  - April 2010, Sanlúcar de Barrameda, Cadiz, Andalusia, Spain
  - April 2009, Rotterdam, Netherlands (Postharvest)
  - April 2009 Agadir, Morocco (Preplant)
  - September 2008, Chengdu, China (Postharvest)
  - August/Sept 2008, Alassio, Italy (Preplant)
  - April 2008, Tel Aviv, Israel
  - July 2007, College Park, MD, U.S. (Postharvest)
  - July 2007, San Jose, Costa Rica (Preplant)
  - April 2007, Alassio, Italy
  - August 2006,Yokohama, Japan
  - May 2006, Dubrovnik, Croatia
- Open-ended Working Group (OEWG) Meetings (makes recommendations to the members of the parties to the Montreal Protocol of the Vienna Convention for the Protection of the Ozone Layer), http://ozone.unep.org/Events/Meetings_OEWG.shtml
  - June 15–18, 2010, Geneva, Switzerland (30th Meeting)
  - July 15–18, 2009, Geneva, Switzerland (29th Meeting)
  - July 7–11, 2008, Bangkok, Thailand (28th Meeting)
  - June 4–7 2007, Nairobi, Kenya (27th Meeting)
  - July 3–6, 2006, Montréal, Canada (26th Meeting)
- Meeting of the Parties (MOP) to the Montreal Protocol on Substances that Deplete the Ozone Layer, http://ozone.unep.org/Events/Meetings_MOP.shtml
  - November 8–12, 2010, Bangkok, Thailand (22nd Meeting)
  - November 4–8, 2009, Port Ghalib, Egypt (21st Meeting)
  - November 16–20, 2008, Doha, Qatar (20th Meeting)

  - September 17–21, 2007, Montreal, Canada (19th Meeting)
  - October 30–November 3, 2006, New Delhi, India (18th Meeting)
- Methyl Bromide Alternatives Workshop, May 11–13, 2010, Kansas State University Manhattan, Kansas
  http://www.ksre.ksu.edu/grsc_subi/Conference/workshop2010/index.html
- Methyl Bromide Pre-shipment and Quarantine Workshop May 5–7, 2010, Visalia, California
- Asia Pacific Conference on Chemical Ecology, October 26–29, 2009, Oahu, Hawaii