National Program 305
CROP PRODUCTION
FY 2013 Annual Report

Contents

Introduction

National Program 305, Crop Production, supports research to develop knowledge, strategies, systems, and technologies that contribute to greater cropping efficiency, productivity, quality, marketability, and protection of annual, perennial, greenhouse, and nursery crops while increasing environmental quality and worker safety.

The Nation's rural economic vitality depends on the ability of growers to produce and market agricultural products – including food, fiber, flowers, industrial products, feed, and fuels – profitably, while enhancing the natural resource base upon which crop production depends. Future financial success depends on increasing productivity, accessing new markets for specialized products, developing technologies to provide new opportunities for U.S. farmers, and utilizing tools and information to mitigate risks and enable rapid adjustments to changing market conditions. The farm sector has great and varied needs driven by a wide variety of resource, climatic, economic, and social factors that require an equally diverse array of solutions.

Contemporary cropping enterprises are complex and depend on highly integrated management components that address crop production and protection, resource management, mechanization, and automation. U.S. annual, perennial, and greenhouse (protected systems) crop production are all based on the successful integration of these components. The development of successful new production systems requires a focus on new and traditional crops; the availability and implementation of improved models and decision aids; cropping systems that are profitable and productive; production methods fostering conservation of natural resources; efficient and effective integrated control strategies for multiple pests; improved methods, principles, and systems for irrigation; improved mechanization; and reduced inputs – all while sustaining or increasing yield and quality.

Production systems must better address the needs of small, intermediate, and large farming enterprises including those using field-, greenhouse-, orchard-, and vineyard-based production platforms, through conventional, organic, or controlled environment strategies. Additionally, adaptation and/or development of technologies are/is required to ensure a sustainable and profitable environment for production agriculture. New technologies must address the need for lower cost, higher efficiency inputs that foster conservation of energy and natural resources, while maintaining profitability and promoting environmental sustainability.

In addition, declining bee populations and honey production require special attention. Over the past several years, a myriad of pests and potentially adverse cultural and pest management practices have been threatening many of the bee species required for pollination of a multitude of crops. Colony Collapse Disorder has now increased losses of the honey bee (*Apis*) to a total mortality of over 30 percent. Also, as new crops or niches are introduced, there is an increasing need for non-honey bee pollinators for specific crops or protected environments.

National Program 305 draws heavily on other ARS National Programs, universities, and industries in adapting and incorporating technologies, approaches, and strategies that enable the advancement of the Nation's agricultural industry and enhanced international competitiveness.

This National Program is divided into two main research components, with several sub-components:

- Component 1: Integrated Sustainable Crop Production Systems
    - Problem Statement 1A: Productive and Profitable Systems for Sustainable Production of Agronomic Crops.
    - Problem Statement 1B: Productive and Profitable Systems for Sustainable Production of Temperate Fruit and Nut Crops.
    - Problem Statement 1C: Productive and Profitable Systems for Sustainable Production of Tropical and Sub-Tropical Crops.
    - Problem Statement 1D: Productive and Profitable Systems for Sustainable Production of Ornamental, Nursery, and Protected Culture Crops.
    - Problem Statement 1E: New and Improved Mechanization
- Component 2: Bees and Pollination.
    - Problem Statement 2A: Bee Management—Improving Bee Nutrition and Performance
    - Problem Statement 2B: Bee Health—Mitigating the Impacts of Pathogens, Pests, and Pesticides
    - Problem Statement 2C: Maximizing Bee Pollination and Quantifying Bee Forage Requirements
    - Problem Statement 2D: Conserving Bee Diversity and Improving Bee Taxonomy

Below are National Program 305 accomplishments from fiscal year 2013, grouped by research component. This report is not intended to be a progress report describing all ongoing research, rather an overview that highlights accomplishments, some of which are based on multiple years of research. As a result, not all research projects will reach an "accomplishment" endpoint each year.

ARS welcomes your input regarding our ongoing research programs. If you have any questions, please do not hesitate to contact either of the co-leaders for National Program 305, Kevin Hackett (Kevin.Hackett@ars.usda.gov) or Sally Schneider (Sally.Schneider@ars.usda.gov).

Component 1:
Integrated Sustainable Crop Production Systems

PROBLEM STATEMENT 1A: PRODUCTIVE AND PROFITABLE SYSTEMS FOR SUSTAINABLE PRODUCTION OF AGRONOMIC CROPS.

Optimizing production practices for new oilseed crops. Camelina and calendula are new oilseed crops in the northern Corn Belt, and there is a lack of information for optimizing production. ARS researchers in Morris, Minnesota, demonstrated that camelina and calendula are not heavy nitrogen users and can be fertilized at lower rates than most common commodity crops. In these studies, camelina had higher nitrogen-use efficiency than its close relative, canola. Farmers producing these crops can save money by using less nitrogen. Researchers discovered that late April to early May was the best time to plant calendula in the northern Corn Belt and that the time from planting to harvest was intermediate to spring wheat and soybean, making it a good rotational crop for this region. Seed yields as high as 2100 lbs/acre and seed oil content of 20 percent were achieved with a new hybrid developed in the Netherlands. Research also identified two new post-emergence applied herbicides (imazamethabenz and desmedipham plus phenmedipham) tolerated by calendula, which now gives farmers more options for controlling weeds in calendula.

Double-cropping with winter camelina in the northern United States. The United States is currently pushing for the development of renewable energy, including biofuels, to replace petroleum. There are some concerns over the economic and social acceptability of using food crops for fuel or using land for growing dedicated biofuel crops that could otherwise be used for producing food. ARS researchers in Morris, Minnesota, demonstrated that camelina grown as a winter annual crop, which can serve as dedicated biofuel feedstock, can be harvested early enough in the following summer to allow production of a short-season food or feed crop such as soybean, sunflower, or millet. Thus, both a biofuel and a food/feed crop can be produced on the same land in a single season. Although double-cropping is more expensive than producing a single crop, research showed that camelina-soybean double crop sequences were both feasible and economically attractive. In one year of the two-year study, the camelina-soybean sequence resulted in net earnings of $70 to $142/acre more than growing a single crop of soybean. Moreover, there was no sacrifice in seed quality of double-cropped soybean, and only a small affect on double-cropped sunflower seed quality over the two-year study. This newly developed cropping strategy allows farmers to produce both biofuel and food or feed on the same land in a single growing season; winter camelina can serve as a "cash" cover crop, which farmers in the Midwest are seeking.

Cotton irrigation and nitrogen fertilization increased yields. Cotton producers are interested in making the most efficient use of irrigation and nitrogen fertilization inputs because these inputs can be quite expensive. ARS scientists in Stoneville, Mississippi, demonstrated that irrigation is an important component in ensuring the most efficient use of the nitrogen that is applied to cotton. In the 2011 growing season, the lint yield of non-irrigated cotton was not improved when 100 lbs nitrogen/acre was applied over the non-fertilized (858 vs. 813

lbs/acre), but when irrigation was applied at 100 lbs N/acre yields were 19 percent greater than the unfertilized (1202 vs. 1013 lbs/acre). No irrigation effects were detected in 2012 due to high rainfall, but nitrogen fertilization continued to increase yields over the non-fertilized. Fiber quality and seed composition were also affected by the irrigation and nitrogen fertility treatments. Using this information, producers can now make better nitrogen fertilization decisions where irrigation is available.

A model species was identified to study the genetics of eriophyid mite host specificity. Eriophyidae is a family of plant-feeding mites that is considered to be among the most promising sources of biocontrol agents for invasive annual grasses, due to their often extreme host specificity. An ARS researcher in Reno, Nevada, in collaboration with scientists at Adam Mickiewicz University, in Poznan, Poland, discovered a complex of cryptic lineages with broadly divergent host ranges within *Aceria tosichella*, a species of eriophyid mite that was previously thought to be a monophyletic generalist feeder. By comparing host-acceptance bioassay data with DNA sequence data from populations of *A. tosichella* collected from a variety of wild and domesticated grass species, lineages were identified with host ranges that varied from highly host-specific to highly polyphagous. In addition to producing results with important agricultural implications (some *A. tosichella* lineages are worldwide pests of wheat, barley, and other cereals, as well as vectors of cereal diseases), these researchers are developing this species complex as a novel model system to study the evolution and genetics of host-specificity in this family of plant-feeding mites with great potential as biocontrol agents of invasive grasses.

Report of the first target-site mutation in a glyphosate-resistant dicot weed species. The widespread adoption of glyphosate-resistant (GR) crops around the world has resulted in the evolution of several GR weed species, including tall waterhemp in Mississippi. ARS scientists in Mississippi discovered that the mechanism of resistance to glyphosate in a Mississippi GR tall waterhemp population is due to a combination of a target-site mutation and a non-target site based mechanism. This is the first report of an altered EPSPS-based resistance in a dicot weed species that has evolved resistance to glyphosate. The GR population absorbed and translocated less glyphosate compared to the GS population. Further, the GR and GS plants contained an equal genomic copy number of EPSPS, which was positively correlated with EPSPS gene expression, unlike EPSPS amplification in a GR biotype of Palmer amaranth (weed species closely related to and with potential to hybridize with tall waterhemp). These finding imply that a grower or land manager could have to contend with a population of tall waterhemp or Palmer amaranth or a mixture of them along with hybrids that may contain genes encoding for multiple mechanisms of resistance, thereby, exploding input costs. This is an important finding to direct the research on glyphosate-resistant weed species.

PROBLEM STATEMENT 1B: PRODUCTIVE AND PROFITABLE SYSTEMS FOR SUSTAINABLE PRODUCTION OF TEMPERATE FRUIT AND NUT CROPS.

Reducing environmental impacts of wine grape production. Better identification of the environmental impacts of wine grape production could help growers facilitate targeted improvement in production system sustainability. ARS scientists in Davis, California, have developed a tool that helps growers and policymakers understand the full environmental impacts of an agricultural production system and identify ways to improve overall efficiency. The Life Cycle Assessment (LCA) tool has been used to assess environmental impacts of wine grape production across a range of vineyard management regimes in two important growing regions of California. The tool evaluates resource extraction; manufacturing of raw materials into products used in wine grape production (e.g., herbicide and fertilizer) and their subsequent transport to the vineyard; activities and energy required to grow the wine grapes (e.g., irrigation and harvest); and final transport of wine grapes to the winery. The tool helped scientists discover a number of alternative management practices, including but not limited to compost, reduced irrigation, and various cover cropping systems that will assist growers seeking to improve the energy use and air emissions of their vineyards.

Attractants for brown marmorated stink bug. The brown marmorated stink bug is an invasive insect pest that causes severe damage to fruits, vegetables, and field crops that has spread to 40 States, as well as to Canada, Switzerland, Germany, and France. A means of monitoring the numbers of stink bugs is necessary for determining when to apply treatments. ARS scientists in Beltsville, Maryland, have confirmed that the bug is attracted to methyl decatrienoate (MDT), a pheromone of a different Asian stink bug species. The researchers have developed and commercialized a new synthesis of this compound for use in monitoring traps. In addition, ARS scientists in Kearneysville, West Virginia, and Beltsville, Maryland, discovered the true male produced aggregation pheromone of the stink bug and confirmed in field trials that it is attractive to male and female adults and immature bugs. The pheromone was developed into a commercial version that has been transferred to the private sector. ARS scientists in Beltsville also discovered that the performance of the bug's pheromone could be enhanced (synergized) by MDT, providing a superior lure for season long monitoring. A patent application has been filed on discovery of the brown marmorated stink bug attractants. It is expected that the commercialization of this pheromone technology will lead to effective management of the pest and new trap-and-kill techniques to reduce pesticide usage.

Excessive iron triggers nickel deficiency. Nickel deficiency not only influences alternate bearing by pecan trees, but also reduces yield and quality of many other crops. Factors affecting the cellular bioavailability of nickel in plants have the potential to influence the health, yield, and quality of plant products. ARS researchers in Byron, Georgia, determined that nickel deficiency is easily induced by excessive iron fertilization or plant exposure to iron. The scientists noted that the iron acts in an antagonistic manner to nickel bioavailability and nutritional physiology. This research identifies an important micro-nutrient interaction in plants that has heretofore been unrecognized and has the potential for practical applications in agriculture. For example, the research identified iron fertilization as

a means of alleviating nickel toxicity in crops, especially those growing on highly mineralized serpentine soils. The findings also highlight the possible existence of iron-induced nickel deficiency occurring in many cropping systems where iron is a fertilizer supplement.

Nitrogen standards for Pinot noir grapevines. Management of grapevine nutrition requires better knowledge of how specific nutrients impact growth, yield, and fruit composition. ARS researchers in Corvallis, Oregon, and collaborators at Oregon State University, developed leaf nitrogen guidelines by growing grapevines in a sand-culture vineyard where nutrient inputs were precisely controlled. Leaf blade nitrogen concentrations of 25 g kg-1 (or 2.5 percent) at bloom and 1.8 g kg-1 (or 1.8 percent) at véraison were required to maintain yields and provide adequate yeast assimilable nitrogen concentrations in berries. Leaf blades were better indicators than petioles for nitrogen and phosphorus status, while petioles were a better indicator for potassium status. Viticulturist's can use this information to manage nitrogen inputs for Pinot noir to ensure that nitrogen status is maintained above the critical values.

Evaluating drought resistance of grapevine rootstock materials. Drought resistance in a cropping system is important as it provides the ability of a plant to continue growth and maintain yield and fruit quality when exposed to periods of water stress. ARS researchers in Davis, California, evaluated the effects of drought on embolism formation and repair in living grapevines; they developed a screening technique to evaluate the hydraulic conductivity of fine roots of grapevines and collected data on numerous grapevine rootstocks ability to withstand embolism spread and repair these blockages. ARS researchers found that the permeability of grapevine fine roots was significantly reduced by drought and varied across rootstock genotypes. These research efforts will provide a better understanding of the patterns of water absorption in grapevine root systems and greatly enhance the quality of fruit and yield in the grape growing industry.

Bioassay provides rapid assessment of the sensitivity of Colletotrichum isolates to fungicides. Fruit rot diseases of strawberry are serious problems for producers in many areas of the world, and they are particularly severe in the southeastern United States where disease is often favored by warm temperatures and frequent rains during the harvest season. Anthracnose diseases caused by Colletotrichum spp. can be especially devastating since they may result in both fruit rot and plant death. Sixteen agrochemicals that are currently used or have been used for control of strawberry pests and diseases were tested in a microtiter assay for in vitro activity against isolates of *C. acutatum, C. fragariae, and C. gloeosporioides* collected from strawberry. Older, protective, multi-site fungicides (chlorothalonil, captan, thiram, and dodine) inhibited the growth of isolates of all three Colletotrichum species at the highest concentration tested. The *C. acutatum* isolates were insensitive to benomyl, thiobendazole, vinclozolin, and iprodione. Two of the newer fungicides in the study (azoxystrobin and cyprodinil) inhibited the growth of most isolates at the lowest concentration. Two commercial formulations of these newer fungicides are now labeled for disease control on strawberries.

Accurate timing of fungicides will control azalea web blight in commercial nurseries. Fungicides are the main tool used to control Rhizoctonia web blight on container grown azaleas, yet accurately predicting when to spray is difficult, making control poor in some years. Fungicide applications were timed by calendar-dates, scouting for disease levels in azalea plants, and weekly rain frequency. Disease control was evaluated on container grown azaleas at two locations for three years. The timing of fungicide applications can be easily implemented by nursery producers by scheduling them on calendar-dates (July 8 and August 1 for the most susceptible cultivars). Scouting also allows producers to adjust calendar-timing in response to a slower or faster disease development due to yearly weather patterns; they look for a threshold of > 30 blighted leaves internally within shrubs. An ARS scientist in Poplarville, Mississippi, developed this knowledge in cooperation with scientists from Auburn University in Auburn, Alabama, and the University of Georgia in Athens, Georgia. The value of scouting is easily justified in comparison to the high cost of fungicides, as scouting requires about 10 minutes per week for an azalea crop that comprises 20 to 50 percent of the plant selection inventory at many ornamental plant nurseries in the southern and eastern region of the United States.

Blueberry seed production and berry quality improves with changes in the shape of flowers. ARS scientists at the Thad Cochran Southern Horticultural Research Laboratory have shown that some blueberry cultivars have flowers that are more easily pollinated by bees than flowers of other cultivars. Fruit quality, in terms of berry size and seed set, improved as longer pistils increasingly exposed stigmas to pollinating orchard bees. Data suggest that shorter flower petals that extrude their pistils as little as 2 mm beyond the opening of the flower make better contact with visiting bees, which ultimately quadruples pollination and seed set, which in turn yields larger, earlier maturing berries. These data imply that plant geneticists, by including floral traits as breeding criteria, could provide farmers with higher yielding blueberry cultivars that can be efficiently pollinated by a greater diversity of bee species.

A *web-based cold temperature prediction system was developed for grape growers*. An ARS Researcher in Prosser, Washington, in collaboration with Washington State University addressed the problem of a lack of vineyard-specific temperature warnings in winter for grape growers whose crops may be damaged by extreme cold. A computer model that used historical data was built to take current temperatures and predict the likelihood of winter damage to several varieties of grapevines in the Pacific Northwest. Nightly information about critical temperatures allows growers to decide whether they need to enact expensive frost-protection measures on any given night. Nightly knowledge that temperatures are not expected to dip below critical values save growers' time and expense in protecting their vineyards for the following growing season.

Organic blueberry production systems. Organic blueberry production continues to grow in the United States with new growers requiring basic information and existing growers struggling to remain economically viable in a global market. An ARS scientist in Corvallis, Oregon, in Cooperation with researchers at Oregon State University, has developed organic production systems with similar yield and production costs to conventional systems. Growers in Oregon and Washington have readily adopted the findings in the use of

landscape fabric in new plantings. Implementation of the practice has increased from less than 10 percent of the newly planted acres in 2006 to more than 80 percent of the new acreage in 2010. The positive effects of landscape fabric on plant growth and yield will likely lead to reduced herbicide application in both organic and conventional plantings.

Defining salinity thresholds for plant function and visual of symptoms in strawberry. Fertilizer application, particularly of N, alters the salinity of soils and soilless growing substrates. In some cases, to levels detrimental to plant production; however, threshold levels of salinity (ECe) have not been well documented in the literature for small fruit and nursery crops. We evaluated the effects of salinity in strawberry and determined that root growth and leaf color were decreased at EC levels > 2.5 dS·m-1, production of daughter stolons and stomatal conductance declined at levels > 3.5 dS·m-1, but levels as high as 4.5 dS·m-1 had no impact on leaf area or stem water potential. Defining salinity thresholds for small fruit and nursery plants will enable growers to identify levels that limit plant function that ultimately result in visual symptoms (e.g., leaf tissue necrosis) and a decline in production.

Weed, water, and nutrient management practices for organic blackberry production. Organic blackberry production has increased to more than 6200 acres worldwide but due to limited information on how to grow the crop organically, there is only 500 acres (as of 2008) in the United States. In cooperation with researchers at Oregon State University, an ARS scientist in Corvallis, Oregon, has identified the best practices to establish and transition to organic blackberry for machine harvest and processing. The information was transferred by eOrganic and is currently being adopted by blackberry growers throughout the Pacific Northwest where over 90 percent of the fruit is processed and more than have the U.S. total is produced. The information will lead to more availability of organic blackberries for consumers in the marketplace.

Reducing pre-harvest germination (Vivipary) of pecan. Pecan crop loss to the germination of nuts while still on the tree (i.e., vivipary) is a major problem for many pecan farmers, especially those in hot arid climates. There is need to develop management strategies that stabilize year-to-year variability in marketable nutmeat yields due to vivipary. ARS researchers in Byron, Georgia, found that vivipary is greatly influenced by trees' exposure to moist soils, with high nitrate nitrogen during the nutmeat filling stage of fruit development and that it is regulated by the plant hormone, abscisic acid. Moist soils and high fruit nitrate prevents timely production of abscisic acid in developing seeds, which prevents seed dormancy. These findings also implicate copper and/or molybdenum deficiency as major contributing factors to vivipary through their influence on the activity of the key enzyme producing abscisic acid. This information enables pecan, and possibly grain farmers, to tailor crop management strategies to reduce loss to pre-harvest germination.

Plant and animal nickel nutrition influences the activity of ribonuclease enzymes. The metabolism of nitrogen is key to a multitude of primary and secondary metabolic reactions in both plants and animals. While nickel is an essential trace element in plants and animals, relatively little is known about its metabolic or physiological roles. ARS researchers in Byron, Georgia, found that a key plant/animal enzyme involved in the recycling of nitrogen

(Ribonuclease A, RNase A) within organisms functions as a urease enzyme in the presence of nickel. This research demonstrates that a non-metallo enzyme, RNase A, exhibits dual activity depending on the presence or absence of nickel and identifies a possible new metabolic role for nickel in plants and animals. The presence of both RNase A and nickel in the spring sap of pecan trees indicates that this enzyme is likely important to the cycling of nitrogen during the early growth phase of many crop species; thus, potentially affecting alternate bearing by pecan trees as well as nitrogen and nickel nutrition management strategies of other crops, especially those exposed to urea fertilizers or transport nitrogen as urea.

Phosphite as a new tool for managing pecan scab. Due to the emergence of fungicide (certain classes) resistance in the scab pathogen (*Fusicladium effusum*) there is need for alternative fungicide chemistries for managing this devastating disease. ARS researchers in Byron, Georgia, found that the simple inorganic molecule, phosphite, registered for use on certain other crops, was highly efficacious in controlling the pecan scab fungus. Phosphite is effective in reducing the disease on young trees as a trunk application, but not on older trees. This research led directly to the registration of phosphite products for use in pecan orchards as canopy sprays in the southeastern United States. The addition of phosphite as an effective alternative fungicide in the pecan 'disease management toolbox' enables growers to minimize the impact of scab and reduces the risk of fungicide resistance developing among existing fungicides used to manage scab.

Improving the accuracy and reliability of pecan scab assessment. Accurate and reliable methods to assess disease are critical to ensure high quality data for comparing treatments statistically; this is required by researchers and for growers who may base management decisions on estimates of disease. ARS researchers in Byron, Georgia, have demonstrated that use of some older category-type scales produces data that has less agreement with actual values and poorer reliability compared to assessments made using the 0-100 percent scale. These results provide the basis for stakeholders (scientists, advisors and growers) to use a rating system that provides data with the highest possible accuracy and reliability, thereby minimizing the risk of error in databased decision-making.

Genetic diversity of pecan scab. The pecan scab pathogen is known to adapt to resistant cultivars of pecan, and knowledge of the pathogen's genetics will provide a basis for improving resistance development in new cultivars to ensure resistance that is more durable. ARS researchers in Byron, Georgia, have now screened a total of 130 SSR markers, and have developed an additional 5 UP-PCR marker and 10 RAPD markers that will be used in studies of genetic diversity, which will lead to improved management of available resistance genes and thus more durable scab resistance.

PROBLEM STATEMENT 1C: PRODUCTIVE AND PROFITABLE SYSTEMS FOR SUSTAINABLE PRODUCTION OF TROPICAL AND SUB-TROPICAL CROPS.

Rootstock impacts on fruit quality parameters in grapefruit. The devastating impact of Huanglongbing on citrus fruit production has spurred increased interest in the impact of

rootstocks on the tree performance in Huanglongbing affected trees. A two year study to determine the effects of rootstock on grapefruit was completed by ARS scientists in Ft. Pierce, Florida. As part of a multiyear rootstock trial, ARS scientists in Ft. Pierce documented significant affects of rootstock on both time of maturity and standard fruit quality parameters (fruit size, peel thickness, fruit shape, total sugar and acid contents). The results are beneficial to citrus producers who must make decisions regarding rootstock selection when establishing new orchards.

Cacao genotypic response to soil flooding. In cacao growing regions frequent high intensity rains are causing soil flooding in the lowland areas; flooding is also a serious problem in cacao nurseries. Anaerobic conditions in the root zone created by flooding affects the biochemical and physiological processes and these have an impact on the growth and development of cacao. Flooding decreased the net photosynthesis, stomatal conductance, and transpiration of flood tolerant and intolerant cacao genotypes. Flood susceptible genotypes showed changes in fluorescence emission, reduction in chlorophyll content, and increased activity of stress enzymes. Flooding also caused changes in macro and micronutrients, total soluble sugars and starch concentrations. Stable plant traits identified in this study will be useful in the identification of cacao genotypes that have tolerance to short periods of flooding. Findings of this study will be helpful to commercial cacao seedling growers to efficiently manage irrigation in the nursery and to farmers to improve cacao production in lowland areas where flooding is a problem.

Cacao genotypic response to soil acidity/aluminum. In tropical soils, Aluminum (Al) is the major mineral component of soil that is highly toxic to crops. In Brazil, cacao is cultivated mainly on Ultisols and Oxisols where Al toxicity and nutrient deficiencies are the major constraints for cacao growth. Experiments were conducted in a greenhouse with several levels of Al to assess its effects on growth, chlorophyll fluorescence, net photosynthesis, and mineral nutrition of two cacao genotypes. Increasing Al concentrations in the growth medium decreased the growth, rate of photosynthesis and its components, and mineral contents. Genotypic differences for tolerance to Al were observed. Existence of genotypic differences for tolerance to phytoxic levels of Al could be useful to breed acid soil tolerant cacao cultivars. Such improved cacao cultivars could reduce the cost of production and enhance yield potentials of cacao crops for the resource poor cacao farmers in Brazil and in the Americas.

Attracting pollinators of atemoya. Atemoya and other fruit crops in the Annonaceae family often have low yield due to poor visitation by pollinating beetles in the family Nitidulidae. Pollination is done by hand in parts of the world, but labor costs are prohibitive in the United States. ARS researchers in Mayaguez, Puerto Rico, demonstrated that commercially available lures for nitidulids (including beetles) attract a variety of species in a dose dependent manner and that the addition of food attractants (bread dough, apple juice, and malt beverage) attracts different species of beetles. We have now begun field trials to demonstrate that this increased number of beetles translates to increased fruit set and fruit size. The lures are substantially cheaper than hand-pollination of multiple flowers per tree. The use of lures will increase the value and market of atemoya.

PROBLEM STATEMENT 1D: PRODUCTIVE AND PROFITABLE SYSTEMS FOR SUSTAINABLE PRODUCTION OF ORNAMENTAL, NURSERY, AND PROTECTED CULTURE CROPS.

Use of biochar as a component in greenhouse substrates. Fertilizers are becoming increasingly expensive due to the energy required to manufacture them or the cost of mining the raw materials. Phosphorus and potassium are two of the primary nutrients used in fertilizers. ARS scientists in Wooster, Ohio, determined that gasified rice hull biochar, a commercially abundant byproduct from the processing of rice, contains a high concentration of phosphorus and potassium, and has potential as an alternative source for use in commercial potting substrates for greenhouse and nursery crops. The scientists determined that the optimal rate for amendment with gasified rice hull biochar into a typical greenhouse potting substrate is 10 percent by volume. At this rate, sufficient phosphorus and potassium are provided for a variety of crop species without additional nutrients being provided. This data provides the industry with baseline information on rates of application that can be used when this product becomes available to the horticultural industry.

Application technology for weed management in nursery ornamentals. Sustainable weed control in container grown pots is difficult because of the need to apply over and through a non-target plant. Large droplet spray applications in field crops have been demonstrated to reduce off-target spray movement. High volume and large droplet weed spray applications were shown to be effective at moving spray down to the substrate surface where preemergent herbicides are most effective. These findings demonstrate how relatively simple changes in spray equipment can be used for container plant weed management while minimizing contamination to operators and off-target areas; helping growers improve worker safety and minimize application amounts.

Tree growth with various fertilizer applications in container production. Because of vast varieties and species in nurseries, scientific guidelines are lacking for growers to improve their nutrition practices based on their specific production circumstance. Fertilizer practices with topdressing, incorporating and liquid feeding methods, can cause substantial labor cost and excessive nutrient runoff loss. To provide solutions to this problem, ARS researchers in Wooster, Ohio investigated various fertilizer practices and nutrient applications for container-grown trees and established a scientific guideline for container production. Following this nutrition application strategy, growers will be able to maximize the one-year growth of container-grown trees, shorten tree production time, and save labor costs.

Generation of ethylene insensitive flowers by inducing expression of a mutant ethylene receptor. Ethylene plays very important roles throughout plant growth and development, including regulation of flower senescence. Plants expressing the dysfunctional ethylene receptor to reduce ethylene sensitivity dramatically extend flower longevity but show a variety of defects including poor germination, poor root growth, and high susceptibility to disease. ARS scientists in Davis, California, have generated transgenic petunia plants in which the mutated receptor is over-expressed under the control of a chemically-inducible system to block ethylene perception. The plants develop normally, and flower longevity is doubled when the chemical inducer is used. Furthermore, when these transgenic petunia

plants were inoculated with *Botrytis cinerea*, disease symptoms on detached leaves and flowers or intact plants were dramatically reduced. This innovative approach overcomes most of defects associated with constitutively inhibition of the ethylene pathway, being able to convert the ethylene sensitive flowers into ethylene insensitive ones, and provides excellent means for controlling flower senescence and improving disease resistance.

Development of Virus-Induced Gene Silencing (VIGS) technology in ethylene insensitive flowers for functional gene analysis. Flower senescence is under tight genetic control and involves changes in the gene expression. To identify a common set of genes that are up- or down-regulated during floral senescence in ethylene insensitive flower species and functional analysis of these genes, ARS scientists in Davis, California, have developed Virus-Induced Gene Silencing (VIGS) technology in ethylene insensitive, extremely short flower longevity (approximately 16 hours from opening to wilting) of flower plant. Results from this study suggested that co-silencing of endogenous anti-viral proteins may increase the range of taxa, including ethylene insensitive species that are amenable to the use of VIGS for functional gene analysis. This technology provides an effective tool to solve what regulates flower senescence and to extend flower longevity in ethylene-insensitive flowers for the ornamental industry.

The daily pattern of high temperature affects grape quality. An ARS researcher in Prosser, Washington, with collaborators at Oregon State University, addressed the problem of how temperature affects the compounds in grapes that are responsible for astringency in wine. The researcher determined that it is not high temperature per se that affects these compounds, but rather the size of the difference between high daytime and low nighttime temperatures that has greatest effect. The potential impact for grape growers in warm climates is to adjust the management of the vines' shoots and leaves to provide some shade to the fruit during the hottest part of the day.

PROBLEM STATEMENT 1E: NEW AND IMPROVED MECHANIZATION

Drift reduction protocol for aerial and ground spray applications. With numerous new spray technologies and methods being developed for drift reduction, standardized measurement and evaluation methods are needed to advise applicators on the degree of drift reduction. ARS researchers in College Station, Texas, working closely with the U.S. Environmental Protection Agency and other research and manufacturing entities, evaluated and refined application protocols and techniques, and developed a generic testing protocol that provides objective and unbiased testing of various drift reduction techniques. The protocol, entitled "U.S. EPA Generic Verification Protocol for Testing Pesticide Application Spray Drift Reduction Technologies for Row and Field Crops," was released by the EPA Office of Pesticide Programs in mid 2013. The document is a critical regulatory resource to assure minimization of drift in agricultural spray applications.

Development of a precision air-assisted sprayer for tree crop production. Trees in nurseries and orchards have great variations in shapes, sizes, canopy densities and gaps between in-row trees. The variability requires future sprayers to be flexible to spray the amount of chemicals that can match tree structures. ARS researchers in Wooster, Ohio, developed a variable-rate air-assisted sprayer implementing high-speed laser scanning technology to

achieve these requirements. Field tests demonstrated that the new variable-rate sprayer produced significantly more consistent spray deposit and coverage inside tree canopies than the conventional sprayers, consequently resulting in less off-target loss and less pesticide use. Therefore, use of the new sprayer to deliver pest control agents will bring great benefits to growers economically and environmentally.

Air velocity distributions inside canopies from the precision air-assisted sprayer. Future precision air-assisted variable-rate sprayers should have a capability to control both liquid and air flows to match tree canopy structures. ARS researchers in Wooster, Ohio established a feasible and economic approach with adjusting fan inlet diameters to achieve the variable air rate function for new precision sprayers used in orchard and nursery applications. With this function, sprayers will be able to control the amount of air flow as needed to prevent crops from being either over sprayed or under sprayed, and to minimize excessive off-target losses to the air and ground, resulting in preservation of air, water, and soil quality and sustainable ecosystems for growers.

System developed for investigation of dynamic droplet impaction and deposition formation on leaves. The need to elucidate droplet dynamic impaction and deposition formation on leaf surfaces to increase the biological control efficiency has been recognized for many years, but recent reports do not address this problem due to lack of scientific methodologies. ARS researchers in Wooster, Ohio, developed a three-dimensional sophisticated system for analyses of dynamic droplet impaction, rebound and deposition formation on leaves. The system was able to manipulate variable droplet sizes, impact speeds and impact angles to independently test the dynamic impaction of droplets on different types of leaves with different spray solutions under controlled experimental conditions. This accomplishment would provide insights into pesticide droplet impaction and deposition formation on plant leaf surfaces to bridge the gaps of knowledge between the spray application technologies and biological control effectiveness. These underlying mechanisms are necessary to advance pesticide spray application technologies and strategies to increase effectiveness and reduce pesticide waste for growers.

Distinguishing glyphosate-resistant (GR) and susceptible (GS) Palmer amaranth (pigweed) plants. A study was conducted by ARS scientists at the Crop Production Systems Research Unit in Stoneville, MS, to determine if glyphosate-resistant and susceptible pigweed could be distinguished using hyperspectral imagery (imagery represented by several wavebands of light). Results showed that GS plants reflected higher light in the visible region of the spectrum compared to GR plants, while GR plants reflected higher light in the infrared region of the spectrum compared to GS plants. A combination of fourteen narrow bands provided a good classification of unknown set of GR and GS plants with a validation accuracy of 94 percent. These results demonstrate that hyperspectral imaging has potential to separate GR from GS Palmer amaranth, and this information has potential to develop a custom camera system to distinguish GR and GS plants from aircraft to allow growers to use selective spraying.

Component 2: Bees and Pollination

PROBLEM STATEMENT 2A: BEE MANAGEMENT—IMPROVING BEE NUTRITION AND PERFORMANCE

High fructose corn syrup and honey bee colony health. When flowering plants are unavailable, beekeepers feed colonies high fructose corn syrup to supplement their diets. ARS researchers in Tucson, Arizona, found significantly larger adult bee populations in colonies fed sucrose syrup compared with those fed high fructose corn syrup. This finding complements earlier studies showing shorter life spans in worker bees fed high fructose corn syrup compared with sucrose. This information allows commercial beekeepers to select better diets for their bee colonies to leave them less vulnerable to loss from environmental fluctuations, parasites, and pathogens.

A rapid, non-destructive method to quantify Queen Mandibular Pheromone (QMP) emissions from honey bee queens. The primary signal of a mated queen, QMP pheromones indicate failing or missing queens to worker bees. ARS researchers in Tucson, Arizona, developed a rapid, non-destructive method to quantify QMP emissions from honey bee queens. Previous methods to quantify QMP required destructive extraction of the mandibular glands to provide an estimate of QMP contents. The new method allows for the repeated measurement of QMP release rates using pheromone exchange between the queen and her workers. Researchers can use this technique to track the effects of colony stressors (i.e., malnutrition, age, disease, agrochemicals) on QMP emissions in individual queens over time. This method will be used to determine the contributions of colony stressors to the excessive queen losses and premature queen replacements widely observed in the beekeeping industry, helping the industry to manage stress on their colonies and prevent excessive queen losses.

In developing honey bee nurses, hypopharyngeal gland gene expression is largely unaffected by protein starvation. Commercial honey bees are subject to periods of nutritional stress, which are implicated in colony losses. ARS scientists characterized diet-dependent differences in honey bee hypopharyngeal gland gene expression using whole transcriptome analysis. Expression in nurse bees fed pollen and honey differed little from those fed only honey. This research will contribute to our understanding of the genetic and physiological changes that occur due to malnutrition associated with commercial beekeeping practices, perhaps suggesting changes in food supplements and their application. (

Overwintered beebread contains a comprehensive nitrogen-processing bacterial community. Overwintered beebread (pollen stored in cells for future colony growth) contains bacterial communities that rapidly degrade beebread. These bacteria include those capable of digesting complex plant polymers (e.g., cellulose and pectin), providing access to the pollen protoplasm. The release of nitrogen rich cell contents of pollen is evidenced by the strong presence of a comprehensive nitrogen processing bacterial community (NPC). These NPC are present at much lower levels in corbicular pollen, suggesting that these bacterial groups are ubiquitous and continuously vectored from plants and the general pollination

environment. These findings indicate a microbial connection between the environment and the preservation and nutritive value of beebread in the hive.

PROBLEM STATEMENT 2B: BEE HEALTH—MITIGATING THE IMPACTS OF PATHOGENS, PESTS, AND PESTICIDES

Varroa mite migration represents a new control challenge. Varroa mites are a major cause of colony losses in honey bees because they parasitize bees and spread viruses in the colony. ARS researchers in Tucson, Arizona, devised a treatment schedule to control Varroa based on colony and Varroa population dynamics. The researchers found that Varroa populations could be kept at low levels throughout most of the summer with this treatment schedule. However, by fall, mite populations were much larger than predicted or than could be accounted for by mite reproduction alone. The researchers determined that mites appear to be migratory and move between colonies with far greater frequency than previously thought. This finding led to changes in recommendations on Varroa control that include a late fall treatment so mite populations remain low over the winter to prevent the loss of colonies in the spring.

Overabundance of viruses in declining colonies. In the largest survey of bee colonies showing signs of Colony Collapse Disorder, ARS scientists in Beltsville, Maryland, showed that they carry a significantly higher diversity and load (amount) of viruses than healthy colonies. Specific viruses linked to decline include deformed wing virus and Kashmir bee virus. The results have bearing on control methods for maintaining healthy bees.

Bee responses to agricultural chemicals. ARS researchers in Beltsville, Maryland, showed significant changes in gene expression for honey bees exposed to agricultural chemicals, indicative of a physiological impact of these chemicals. Immune system genes showed altered expression in adult bees exposed to acaricides used for mite control. Both immune and detoxification genes changed in larval bees raised with sublethal levels of a range of herbicides, insecticides, and mite control agents. These results are being compared to field and laboratory morbidity trials in order to help identify risks of bees to specific chemicals. The results help inform decisions on labeling and usage requirements for agricultural chemicals, protecting bees from those chemicals to which they are especially sensitive.

Interactions between honey bee disease agents and pesticides. A long-term field and experimental study pointed toward an increased susceptibility of honey bee workers toward the gut parasite *Nosema ceranae* after exposure to imidacloprid. The results suggest that beekeepers should be especially alert to *Nosema* risk following insecticide exposure, and should manage their bees accordingly.

Ozone fumigation as a disinfectant for honey bee comb. ARS scientists in Logan, Utah, demonstrated that ozone is useful for decontaminating honey bee hives, as it can break down pesticides, kill insect pests, and kill pathogen spores. Honey bee hives typically get moved between colonies and can potentially spread pests and disease, so a decontamination method is needed. Ozone should also prove useful as a means to fumigate alfalfa leafcutting bee

nesting boards to reduce the spread of chalkbrood in this managed bee. This fumigation method will help safeguard the health of beekeepers hives.

Variation in honey bee resistance to deformed wing virus. An important, but relatively unstudied, component of honey bee mortality associated with *Varroa* mite infestations is the response of honey bees to the deformed wing virus that the mite transmits. ARS researchers in Baton Rouge, Louisiana, studied the response to *Varroa* in a large number of commercial honey bee stocks and found that they varied in the onset and severity of deformed wing virus symptomology, independently from the intensity of *Varroa* infestations. This discovery opens the way to selecting honey bees for commercial pollination that are resistant to both varroa mites and Deformed Wing Virus.

PROBLEM STATEMENT 2C: MAXIMIZING BEE POLLINATION AND QUANTIFYING BEE FORAGE REQUIREMENTS

Chemistry of nesting attractants identified for alfalfa leafcutting bees and blue orchard bees. It has long been known that alfalfa leafcutting bees (ALB) and blue orchard bees (BOB), both solitary-nesting bees, are attracted to old nesting sites. For BOB, ARS scientists in Logan, Utah, and Fargo, No. Dakota, identified chemical cues responsible for nest selection, and then developed artificial nest attractants based on some of these compounds. A commercial product is currently being evaluated. ARS scientists found that only some components of old nests are attractive to ALB, but have not identified the critical chemical components. Attractants will allow farmers to retain more bees in desired locations.

Methods developed for propagating and releasing blue orchard bees in large, commercial orchards. ARS scientists in Logan, Utah, developed a field incubation box, portable nesting shelters, and protocols for using blue orchard bees to pollinate almonds, apples, and cherries. In addition, methods were developed for increasing bee forage by planting early-flowering herbaceous plants in or near orchards. The potential utility of this bee has spurred the formation of a new organization of blue orchard bee producers and users, the Orchard Bee Association. Some blue orchard bee producers are propagating these bees in large screened enclosures using the recommended flowers. California almond growers have adapted this approach to extend bee forage for honey bees.

Western bumble bees developed as greenhouse pollinators. Tomatoes and other crops grown in greenhouses require bumble bee pollinators. Unfortunately, the only commercially available bumble bee is native only to the Eastern United States; plus it might be associated with the accidental introduction of exotic diseases that could potentially affect wild bees in the western United States. ARS scientists in Logan, Utah, developed methods for the mass production of four western bumble bee species. As a result of this research, two commercial bumble bee production companies (which supply over 95 percent of all commercial bumble bees) are developing western species for commercial use.

PROBLEM STATEMENT 2D: CONSERVING BEE DIVERSITY AND IMPROVING BEE TAXONOMY

Largest collection of bees in the world. ARS houses the U.S. National Pollinating Insects Collection in Logan, Utah, is one of the largest collections of bees in the world, containing approximately 1.1 million specimens. This reference collection is visited and used by scientists from all over the world. Data from the insect labels, including the identity, date and time of collection, host plant, gender, etc., has been entered into a specimen-level relational database for 874,548 of the specimens in the collection and is available to the scientific community. The ARS dataset is included within the larger, cooperative research tools of the Global Biodiversity Information Facility and DiscoverLife websites, making it broadly available to the scientific community.

Native bees assist efforts to restore damaged Federal lands. Land managers in the western United States need affordable native plant seed for re-vegetation efforts after wild fires and overgrazing by livestock. ARS scientists in Logan, Utah, experimentally characterized the pollination needs of 12 Western wildflowers, surveyed their native pollinators, and identified pollinators that are practical for the commercial production of these plants as specialty seed crops. This was part of a high profile, multi-agency, Federal research program, and has allowed seed growers to produce native plant seeds.