Component II: Protection of Agricultural and Horticultural Crops

2l. Cotton (U.S. Value 2007: $5.2 billion)

***Problem Statement*:** Cotton does not produce maximum yields in the United States because of realized and potential constraints characterized by the following insect pests, weeds, and knowledge gaps:

- Piercing-sucking insects (e.g., lygus bug, cotton fleahopper, stink bugs, green mirid, cotton aphid, whiteflies) that cause about one third of all insect damage to cotton
- Development of resistance to insecticides or to bacterial toxins in transgenic (Bt) cottons by cotton insect pests
- Continued presence of the boll weevil and pink bollworm, necessitating ongoing research support to ensure eradication progress and efforts are sustained
- New introductions of invasive arthropod species requiring improved detection, monitoring, and remediation methods
- Herbicide-resistant native weeds (e.g., morningglories, redvine, trumpetcreeper, spreading dayflower, smartweeds), exotic weeds (e.g., Benghal dayflower, nutsedges), and naturally herbicide-tolerant weeds (e.g., pigweeds, horseweed) requiring improved knowledge of weed biology and management
- Weed propagule persistence and dispersal of weed populations (seedbanks) and implications for weed management (e.g., black nightshade, browntop millet, prickly sida, barnyardgrass, florida pusley, wild poinsettia, spurges, Texas millet)
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***Research Needs*:**

1. **Piercing-sucking Insects**

   Importance: Plant bugs and stink bugs have become the most important pests of cotton in the United States. Although the speciescomposition of individual complexes of these pests vary regionally, key species or groups of species produce economic losses annually in western (western tarnished plant bug), southwestern (cotton fleahopper, green mirid), mid-South (tarnished plant bug) and southeastern (stink bugs) production regions. The importance of plant bugs as pests has increased, at least in part, because the adoption of insecticidal transgenic varieties and progress in eradicating the boll weevil have led to reductions in the use of insecticides that once provided incidental control of piercing-sucking pests. Other piercing-sucking pests, such as whitefly and aphids, continue to be problematic in several regions of the United States cotton belt. This insect complex has long been associated with a variety of impacts on cotton lint yield and quality, including lint contamination by honeydew, production of immature fibers, discoloration from boll feeding and associated boll rot, and delayed crop maturity resulting from early- and mid-season square loss.

Research Gaps: Sucking insects in many cotton production systems have received relatively little research attention compared to more traditional cotton pests such as the boll weevil, cotton bollworm, tobacco budworm, and pink bollworm. Consequently, knowledge of certain aspects of the basic ecology, population dynamics, and crop-pest interactions, as well as fundamental knowledge of sampling methods, economic thresholds, and control efficacy are lacking. Increased knowledge of these factors will be necessary for development of ecologically-sound and sustainable management strategies that focus on a broader landscape-level perspective. Because the economics of commercial agriculture dictates continual changes in production practices, increasingly sophisticated knowledge of ecological mechanisms driving population and landscape-level processes will be needed to ensure the durability of management strategies. For example, the USDA, ARS Area-Wide Control Program for Tarnished Plant Bug demonstrated that treating marginal areas (turn rows, ditches, roadsides, etc.) with a selective herbicide to control broadleaf hosts of the pest reduced in-season cotton insecticide costs by $5.90 per acre. Recent market-driven increases in acreages of alternate cultivated hosts (corn, soybean), however, have reduced the benefits of the program. Development of more cost-effective, environmentally-sound, and durable management strategies for the complex of piercing-sucking insects will, therefore, require extensive knowledge of spatial and temporal population patterns occurring in a landscape containing a mosaic of hosts. Interpretation of landscape-level data will require increased understanding of sampling methods and their limitations. We need to elucidate crop responses to infestation, improve sampling methods, and assess the risk and status of pesticide resistance to construct more reliable action thresholds that maximize profitability of production. (Also, see the Legume subcomponent for additional information on lygus and stink bug research.)

Actions: ARS will:

Monitoring/Decision Aids

- Evaluate and calibrate standard and novel sampling methods for plant bugs in cotton.
- Develop and refine economic thresholds for sucking insects in cotton.
- Develop and validate GIS map-based risk-rating systems for stink/leaf-footed bugs at whole farm and field levels.
- Define spatial and temporal distributions of pests and natural enemy populations.
- Identify pheromones (sex, aggregation, defensive) with application in monitoring and mating disruption of piercing-sucking pests.

Host-Insect Interactions

- Examine host plant responses to plant bug injury on species- (Pima or Upland) and cultivar-specific bases.
- Examine virus-vector relationships and identify plant pathogens vectored to cotton by stink bugs and cotton fleahoppers.

Basic Biology/Ecology

- Identify endogenous and exogenous factors influencing diapause in plant bugs and define the ecological implications of the diapause phenomenon.
- Characterize dispersal of plant and stink bugs between and within multiple hosts using mark-recapture and pollen identification.
- Identify neuropeptides that regulate critical life processes of stink bugs.
- Illuminate the process of hormonal regulation of development and reproduction in plant bugs.
- Study and implement novel molecular-based control strategies for whitefly and plant bugs.
- Identify and functionally characterize genes/proteins in sucking cotton pests with application for disruption of key physiological processes.
- Develop molecular phylogeny of lygus bugs

Control, Biological

- Evaluate selected insect pathogens for incorporation into an ecologically-based management strategy for plant bugs.
- Develop and test habitats of nectar-producing plants for conservation of stink bug natural enemies and bees in conventional and organic production of cotton.
- Evaluate release strategies of the stink bug egg parasitoid, *Trissolcus basalis*, for augmentative biological control in cultivated crops acting as sources of stink bug populations.
- Develop DNA-based methods for studying and quantifying predation on piercing-sucking pests.

Control, Chemical

- Evaluate insecticides for selectivity for piercing-sucking pests and minimal impact on natural enemy complexes.

Control, Landscape Management

- Elucidate relationships and interactions between landscape structural parameters, and pest biology and dispersal behavior.
- Develop and evaluate trap cropping systems for stink/leaf-footed bug management that are adaptable to conventional and organic production systems.
- Evaluate non-crop hosts for use as trap environments.
- Identify plant volatiles used in host attraction and recognition.
- Conduct flight mill studies of the flight behavior and activity of plant and stink bugs.

- Develop methodologies to use elemental isotopies or genetic markers to better understand the ecology of plant bugs, thereby improving delivery of areawide control methods and novel insecticide resistance management strategies.
- Develop and apply computer simulation models of IPM strategies over large landscape scales.

2. Insecticide Resistance and Management

Importance: Insecticides remain a primary tactic of pest control in most cotton IPM programs throughout the United States, and insecticide resistance remains a continual threat to the sustainability of these management programs. Tarnished plant bugs in the mid-south have, or are developing resistance to a range of insecticide classes. Whiteflies have a long history of insecticide resistance, and it is possible for the Q biotype, which is resistant to most current insecticides used in whitefly management, to become established. Also, several caterpillar pests have shown the capacity to evolve resistance to Bt proteins in the laboratory. Therefore, field-evolved resistance to Bt-cotton is a critical concern. New strategies for managing insecticide resistance are needed to delay or prevent the onset of resistance and sustain the current arsenal of pest management tools.

Research Gaps: Critical research needs include improved methods for resistance monitoring, as well as development of new insecticide resistance management strategies and control tactics to augment the limited selection of insecticides currently effective against major cotton pests. New information is needed on the population ecology/genetics of Bt-targeted pests so that resistance management strategies can be optimized, and new control methods can be integrated in a way that improves the quality and duration of this pest control technology.

Actions: ARS will:

Resistance monitoring

- Continue to monitor the development of insecticide resistance in the tarnished plant bug and characterize the mechanisms of resistance. This will aid in the development of new control methods with unique modes of action and assist in the implementation of optimal insecticide rotation schemes to delay the evolution of resistance.

Control, Biological

- Develop and enhance the use of a new biotype of the fungus *Beauveria bassiana* for control of tarnished plant bug in the areawide program and as a rescue treatment during the cotton growing season.
- Study movement and mating behavior of Bt-targeted pests in diverse cotton agroecosystems to optimize the management of Bt susceptibility in the pest populations.

Control, Resistance

- Use existing genetic markers and develop new, more informative, genetic markers to study population parameters such as gene flow of rare resistance alleles, to improve resistance management strategies for Bt cotton.
- Provide expertise and support of programs for monitoring pink bollworm resistance to Bt cotton.
- Characterize Bt intoxication and mode of action processes in pink bollworm, tobacco budworm, and cotton bollworm.
- Study transposable elements derived from pink bollworm and adapt novel molecular tools used for increased gene drive and transformation systems in other insect systems for improved control options.
- Examine the influence of plant allelochemicals on insecticide resistance expression in the polyphagous sweetpotato whitefly.
- Refine chemical control strategies for sweetpotato whitefly to manage resistance and enhance natural enemy conservation.

3. Sustaining Eradication of Boll Weevil and Pink Bollworm

Importance: Over a period of about 30 years, the boll weevil eradication program has eliminated the insect as an economic pest from nearly 14.9 million acres of U.S. cotton; it is still active in 1.45 million acres. Despite considerable progress in eradicating the boll weevil, low-level infestations remain in many production regions of the South and Southwest. Occasional captures of weevils in suppressed or eradicated zones trigger expensive and labor-intensive remediation measures to preserve prior program investments. The pink bollworm eradication program was initiated in early 2000 in Texas and has spread west to Arizona and California, with eradication activities in the United States as a whole scheduled to end in 2010. Both eradication programs represent vast investments of producer, state, and Federal resources, and both programs are subject to the continual threat of reinfestation from Mexico, where both pests remain established.

Research Gaps: There is need for research support of maintenance programs, especially regarding detection and monitoring of re-infestations that jeopardize the substantial investments in these eradication programs. The current economic environment dictates reductions in the cost of maintenance programs concurrent with improved capacity to detect and remedy re-infestations. These needs are particularly urgent for program areas that abut international borders. Elimination of low-level populations in active programs, and efficient detection of local and distant sources of re-infestation, will require improvements in monitoring technology and interpretation of trapping data, and increased understanding of biotic and abiotic mechanisms governing insect movement and subsequent colonization. Determination of the origin of reinfestations is crucial to effective eradication maintenance strategies. Monitoring remaining populations of boll weevils for susceptibility to organophosphates in the United States or Mexico is important to ensure that effective control can be achieved in potentially re-infested zones.

Actions: ARS will:

Identification and Detection

- Determine if molecular markers can be used to identify populations of remaining boll weevils in the United States and Mexico.
- Develop technology and techniques for rapid identification and biochemical characterization of pollen attached to boll weevils.
- Develop techniques to detect and map uncultivated areas of volunteer cotton plants using remote sensing.

Monitoring

- Monitor remaining populations of boll weevils for susceptibility to organophosphates, and develop alternate control strategies in the event of resistance development.

Control

- Evaluate and develop new technologies and strategies for managing pests in post boll weevil eradication zones.

4. Introduction of Invasive Arthropod Species

Importance: Invasive species are a growing problem in the United States. In 2000, it was estimated that invasive arthropods caused $20.5 billion dollars in losses and control costs annually. It is estimated that approximately 40 percent of all crop pests are exotic and many agricultural commodities are at risk from invasive species. Vigilance is required to identify and act on emerging exotic pest issues before they become problematic.

Research Gaps: In many cases, monitoring techniques, such as using sex pheromone and floral volatile lures, are available. Therefore, early detection of certain key exotic species (e.g., *Helicoverpa armigera*, cotton bollworm; *Spodoptera littoralis*, Egyptian cotton leafworm; and *S. litura*, cotton leafworm) is important so that control strategies can be implemented while populations are low and amenable to eradication. Both exotic species of *Spodoptera* attack several crop plants, and *S. litura* has been found in south Florida where it presumably was imported on ornamental plants from Asia. These species have wide host ranges and it is conceivable that these species could invade subtropical areas of the United States (Florida, Texas, Arizona, and California) on crops other than cotton and then expand their range to include cotton-growing areas. Cooperative research between ARS and APHIS scientists will be needed to monitor these exotic lepidopteran species.

Actions: ARS will:

Monitor

- Monitor for populations of key exotic species.

5. Management and Biology of Herbicide-resistant and Herbicide-tolerant Weeds

Importance: Herbicides are the primary means of controlling weeds in cotton. The use of glyphosate (Roundup, among others) in Roundup Ready cotton has altered crop production practices, allowing for greater adoption of reduced tillage and more efficient weed control of many previously troublesome species (such as sicklepod and Johnsongrass). However, this selection pressure has caused shifts in weed species composition towards weeds that are naturally tolerant of or resistant to glyphosate, or that can develop from seedling to maturity, from layby to harvest. This issue is further complicated by the co-occurrence of weeds resistant to other herbicides used in cotton (and crops commonly used in rotation with cotton), which could potentially lead to the evolution of weeds resistant to multiple herbicides. If herbicide-tolerant and herbicide-resistant weed biotypes are allowed to spread, there will be a clear reduction in the ability of the grower to effectively manage weeds. The presence of herbicide-resistant weeds threatens the use of reduced tillage systems, which promotes soil conservation, but precludes an alternative control option (i.e., cultivation). Many of the weed species that are troublesome in cotton are also difficult to manage in summer crops (e.g., corn, soybean, and peanut) that are commonly rotated with cotton and planted in the same fields. This is especially true of herbicide resistant weeds, as these crops use herbicides with similar modes of action. In addition to use in cotton, ALS-inhibiting herbicides, dinitroanilines, PPO-inhibiting herbicides, chloracetemides are also used in corn, soybean, and peanut. Glyphosate, ureas, and triazines are also used in both corn and soybean. Further complicating this issue is the disappearance (e.g., cyanzaine/Bladex) or threat of disappearance (e.g., MSMA) of tools commonly used to manage weeds prior to the introduction of herbicide-tolerant crops.

Research Gaps: There is great variability in the mechanisms of resistance and tolerance in many of the troublesome weeds that have developed in our agroecosystems. Some species have the ability to restrict herbicide movement within the plant, but the mechanisms for this are not understood. With other species, such as glyphosate-resistant pigweeds and glyphosate-tolerant Benghal dayflower, the means of resistance and tolerance have not been fully understood. Resistance to other herbicides used in cotton has been documented worldwide, for example, ALS-inhibiting (e.g., Staple), dinitroaniline (e.g., Prowl), PPO-inhibiting (e.g., Relfex), organoarsenicals (e.g., MSMA), and bipyridilium (e.g., Paraquat) herbicides. However, as the occurrence of glyphosate-resistant weeds increases, alternatives to glyphosate-only applications are replaced with tank-mixes that include alternative herbicides. The use of glyphosate will likely continue, even in areas with resistant weeds, due to its high efficacy against numerous common weeds. Selection of tank-mix partners to which resistance does not compromise control will have limited application. Alternative weed management options to be used in place of, or in conjunction with, glyphosate in cotton and its rotation crops need further exploration. In addition, while herbicide resistance mechanisms are presently unknown in many of these resistant weeds, it is unlikely that these mechanisms would prevent the infectivity mechanism and mode of action of a bioherbicide that is pathogenic to non-herbicide resistant weed biotypes.

Actions: ARS will:

- Determine basic mechanisms of herbicide-tolerance or resistance in troublesome species, such as horseweed, ragweeds, johnsongrass, pigweeds (e.g., waterhemp and Palmer amaranth).
- Investigate basic biology of vines with herbicide-tolerance or -resistance, such as morningglories and redvine.
- Evaluate various herbicide and cultural crop production practices to suppress herbicide-resistant and herbicide-tolerant weed species, and weeds developing late season between layby and post-harvest.
- Investigate the use of plant pathogens as bioherbicides for weed species [e.g., horseweed, pigweeds (including Palmer amaranth and waterhemps), ragweeds, morningglories, redvine, and trumpetcreeper] that have become resistant or are naturally tolerant of commonly used herbicides.

6. Persistence and Dispersal of Weed Populations (weed propagule) and Implications for Weed Management (seedbank)

Importance: Current weed management strategies focus on controlling emerged weeds or reducing seedling emergence. These efforts will effectively reduce emerged weed population densities. However, these results are temporary, and treatments must be repeated throughout the season to minimize crop yield losses from weeds. To improve efficiency of these strategies, greater understanding of the factors and mechanisms that govern the reproduction, dispersal, and establishment of weeds in cotton production systems is needed. Reproduction and dispersal of seed and vegetative propagules (e.g., nutsedge tubers) with differing types and levels of dormancy and longevity lead to a reserve in the seedbanks and propagule-banks for future weed populations. Factors that regulate seedbank and propagule-bank dynamics are not well understood in cotton agroecosystems. Greater knowledge concerning the fate of weed propagules and factors that regulate propagule dispersal and viability will assist in developing strategies to reduce weed populations for greater long-term weed control and will assist in improving weed management efficiency.

Research Gaps: Comprehensive understanding of weed reproduction is lacking for most weeds that commonly occur in cotton production systems. Because of the limited basic and applied knowledge of factors that affect weed establishment, growth, reproduction, dispersal, and seed fate, there has been limited success in minimizing weed population densities in the soil seedbank. More information is required concerning factors that govern weed seedling establishment, pollination efficiency, seed development, seed rain and dispersal, and seed dispersal within and between fields, especially for weeds without specialized dispersal mechanisms.

Actions: ARS will:

- Investigate the seedbank dynamics and factors that regulate seed persistence of troublesome weeds (e.g., Benghal dayflower, pigweeds, browntop millet, and nutsedges) of cotton and its common rotational crops.
- Evaluate the dispersal mechanism(s) of Texas weed, croton species, vetch species, wild geranium, and other principal weeds of fields in the mid-South that eject their seeds from the capsule and investigate inhibitors of these processes for potential field use.

***Anticipated Products*:**

- Increased knowledge of sucking pest biochemistry, biology, ecology, behavior, dispersal, and genetics.
- Increased knowledge of biological control agents, sampling methods, decision aids, host plant interactions, and other potential control tactics such as trap cropping.
- GIS methods, computer simulation, and various genetic and marking techniques for all cotton production areas of the United States that exploit an understanding of the landscape ecology of piercing-sucking pests and their natural enemies.
- Increased knowledge of pest semiochemicals and their use in monitoring and management.
- Understanding of the pest biology and behavior (attractants/repellents), and plant injury relationships between piercing sucking pests and their host plants.
- Identification of potential pathogens useful in plant bug control and better understanding of potential plant-pathogen/pest relationships.
- Improved/new insect pathogenic biological control agents
- Strategy for augmentative biological control for management of stink/leaf footed bugs.
- Improved methods for the detection and study of predation on sucking pests.
- Improved conservation of natural enemies through use of selective insecticides and provisioning of nectar and other non-prey resources.
- Improved monitoring systems for tracking insecticide resistance and resistance to transgenic Bt cotton.
- Improved resistance management systems for delaying resistance and sustaining important insecticides and transgenic technologies.
- Increase knowledge of the underlying genetics and behavior of resistance.
- Improved monitoring of eradicated pests to allow more efficient remedial actions.
- Improved monitoring of potential exotic invasive pest species.
- Determination of the mechanism(s) by which resistance and tolerance to glyphosate is achieved and possible alternative treatments that would allow for control of these species.

- Effective weed management strategies for minimizing the impact of herbicide-tolerant/resistant weed species in conservation tillage and conventional tillage agroecosystems.
- Improved long-term weed management systems that incorporate knowledge of soil seedbanks and seed longevity into the design of crop production systems and weed control decisions.
- Knowledge of the mechanism(s) of seed dispersal will allow development of seed dispersal process inhibitors and treatments that would affect cotton boll opening and seed shatter in soybean and rape.
- Development of a broad-spectrum bioherbicidal fungus tactics that provide good to excellent control of the cotton weed species and include directed spray application technologies and/or preplant applications for use in row crops such as soybeans and cotton.

***Potential Benefits (Outcomes)*:**

- Strategies for more efficient, sustainable and ecologically-based IPM systems for all pests of cotton.
- Reductions in crop and quality loss from insect pests of cotton.
- Reductions in insecticide use and in overall costs of pest management.
- Improved quality of rural communities.
- Reduced impact of weeds, especially those that tolerate or are resistant to current weed control options, on cotton production systems through improved weed management strategies.
- Improved control and management of troublesome species due to a greater understanding of the population dynamics of herbicide-resistant and herbicide-tolerant weeds.
- Greater efficiency in weed management systems due to improved knowledge of weed reproductive biology and factors that regulate seed longevity in the soil propagule/seedbank.
- Improved bioherbicide performance due to optimization of mass production, improved formulation and application technologies, and increased knowledge of ecological/climatological effects, e.g., weed and crop densities, rainfallfastness of pathogen formulations, and weed growth stage.
- Tactics for optimal application timing of candidate bioherbicide and models for predicting bioherbicide efficacy due to an understanding of weed and pathogen biology, ecology, and biochemistry.
- New and improved commercial bioherbicide products available to the public for weed control.

- Reduction and minimization of weed shifts impacts resulting from continuous glyphosate usage.
- Improved resistance management strategies due to better understanding of resistance establishment pathways.

USDA ARS Resources:

- Areawide Pest Management Research Unit, College Station, Texas
- Beneficial Insects Research Unit, Weslaco, Texas
- Crop Protection and Management Research Unit, Tifton, Georgia
- Insect Behavior and Biocontrol Research Unit, Gainesville, Florida
- Pest Management and Biocontrol Research Unit, Maricopa, Arizona
- Southern Insect Management Research Unit, Stoneville, Mississippi
- Southern Weed Science Research Unit, Stoneville, Mississippi
- Western Integrated Cropping Systems Research Unit, Shafter, California