Component II: Protection of Agricultural and Horticultural Crops

2k. Corn (U.S. Value 2007: $52 billion)

***Problem Statement*:** Control costs and losses from insects and weeds in the United States corn crop add to over $2 billion annually. Growers are unable to increase corn production with emerging control technologies because of the following pests, weeds and issues:

- Pest Resistance to Bt Corn and Chemical Insecticides and Glyphosate Tolerant (GT) Weeds in GT Crops
- System Level Problems with Pests Associated with New Types of Corn, Cropping Systems and Management System Diversity
- Environmental Stewardship: Impact of Pest Control Systems
- Developing and Using New Technologies
- Emerging Pest Problems and Issues Related to Biofuel Production
- Key Insect Pests and Weeds:
  - Corn Rootworm (*Diabrotica* spp.) (throughout Corn Belt and southern states)
  - Corn Borers: European corn borer (Corn Belt states); Southwestern Corn Borer (Kansas, Missouri and southern states); Sugar Cane Borer (Louisiana and Texas)
  - Corn Earworm and Fall Armyworm (primarily southern Corn Belt states)
  - Western Bean Cutworm (emerging pest in Nebraska, Iowa, Illinois)
  - Spider Mites (Texas and Kansas) [no ARS work planned]
  - Kernel Feeding Pests: Brown and Green Stink Bugs, Sap Beetles, Pink Scavenger Caterpillar (primarily southern states)
  - Annual Local Grass Weeds: Broadleaf Signalgrass, Browntop Millet, Junglerice, and Shattercane (southern Corn Belt, especially regarding herbicide sensitivity; e.g., resistance to ALS-inhibitor herbicides)
  - Annual Broadleaf Weeds: Giant Ragweed and Horsetail (marestail) (evolved resistance to glyphosate throughout Corn Belt); Palmer Amaranth (evolved resistance to glyphosate in central to southern Corn Belt); waterhemp (evolved resistance to glyphosate in central to northern Corn Belt); Benghal dayflower (natural resistance to glyphosate, southern Corn Belt); Asiatic dayflower (natural resistance to glyphosate, central Corn Belt); lambsquarters (rapidly increasing frequency of poor control by glyphosate throughout Corn Belt)
  - Perennial Grass Weeds: Johnsongrass (resistance to ALS-inhibitor herbicides in southern Corn Belt); cogongrass (southern Corn Belt); Quackgrass (northern Corn Belt organic production)

- Perennial Broadleaf Weeds: Canada thistle (northern Corn Belt organic production); White Cockle and Pokeweed (northern Corn Belt)

***<u>Research Needs</u>*:**

1. **Pest Resistance**

Importance: Collectively, corn rootworm, European corn borer, southwestern corn borer, corn earworm, fall armyworm, western bean cutworm and a number of kernel feeding insects reduce corn grower yields at least 5-10 percent and impact grain quality. Damaged corn tissue, especially ears, can lead to fungal infections (molds) and the development of mycotoxins, especially aflatoxin and fumonisin which are unsafe to livestock and humans. Weeds cause growers to incur costs directly through yield losses and herbicide and equipment purchases, but also indirectly through increased labor, application (fuel) expenses, harvesting difficulty, and grain contamination. Weeds also serve as alternate hosts for some important crop diseases and insects.

U.S. growers are becoming more and more dependent on transgenic crops for insect and weed control. Widespread use of this technology, however, increases the likelihood that pests will become resistant to these corn products. Fall armyworm larvae in Puerto Rico have become resistant to Cry1F Bt corn and a number of weeds have become resistant to glyphosate. Resistance management programs are necessary to prolong the use of these environmentally friendly and popular products. Additionally, growers in the South and sweet corn producers are threatened by the development pyrethroid resistant corn earworm. Besides evolved resistance, some pests are naturally tolerant to some commonly used pesticides. The term "species shift" describes encroachment into an agroecosystem of naturally tolerant pests in response to repeated use of the same or related pesticides. Species shifts are increasingly noticeable and troublesome in systems dominated by glyphosate-resistant crops.

Research Gaps: Problems with resistant weeds and insects have created an urgent need to better understand the biology, ecology, and genetics of these pests. In particular, there is a need to understand the mechanisms and inheritance of resistance, factors that influence the adaptation of these traits, and movement of resistance genes across landscapes. Increased knowledge in these areas can be used to mitigate resistance issues as they appear and can be used in the development of future management products. For insect resistance management (IRM) of Bt corn, growers are required to plant 20 percent refuge (i.e., non Bt corn) but this is becoming increasingly more difficult as seed companies stack multiple insect and weed control products together. However, there is an opportunity with new types of Bt corn to make IRM easier for growers. Smaller refuges and even seed blending might be possible but there are many questions related to insect movement that influence the development of insect resistance. Evolution of resistance often is accompanied by changes in behavior, development, physiology, and responses to the environment and host plant. Identification and understanding of these changes are important because they affect how resistance spreads and persists in populations, and this influences strategies for mitigation. There also is a need to develop

more efficient monitoring systems for detecting insects resistant to transgenic corn and chemical insecticides and weeds resistant to various herbicides.

Actions: ARS will:

Control

- Utilize stable carbon isotope techniques to identify potential differences in source crops for pyrethroid-resistant and susceptible corn earworms.
- Improve and expand pyrethroid resistance monitoring for corn earworm.
- Develop and incorporate new control strategies into an IRM plan that includes rotation of insecticide chemistries.
- Develop lines of the western corn rootworm selected to survive transgenic corn, utilize these rootworm lines toward an understanding of rootworm survival on transgenic corn, and if possible, evaluate these lines on other transgenic maize lines for potential cross resistance.
- Improve knowledge of corn rootworm (adults and larvae) ecology, genetics, and behavior in relation to the efficiency of IRM plans and European corn borer.
- Examine changes in flight behavior and development times of insects selected in the laboratory for Bt resistance.

2. System Level Problems with Pests

Importance: Solutions to specific challenges with pest management can influence the decision-making process of other farm management practices. Systems-level understanding of the implications of pest management decisions provide a real-world test of how specific decisions influence farm productivity. These systems-level projects are particularly important in understanding the ecological impacts of genetically enhanced crops, consequences of low- vs. high-diversity cropping and management systems, key differences between organic and conventional approaches to farming and managing pests, and the effects of landscape level processes on within-field distributions of pests and natural enemies.

Research Gaps: A basic tenet of IPM systems is that technology to control pests should be applied only when economic and environmental return justifies the control. The implications of prescriptively planting and managing genetically enhanced crops (Bt-expressing or herbicide-tolerant) on environmental (biodiversity, other pest management options) and economic (costs and returns) aspects of crop production relative to other pest management strategies need to be evaluated using systems-level approaches in ways meaningful to growers. Organic producers are faced with unique pest management challenges including a limited number of options when it comes to managing weeds and insects. A solution to this problem involves understanding how specific farm management practices and their various combinations promote crop health and natural enemies and minimize pest populations and damage. Predicting spatial patterns of pest pressure between and within fields, farms, and regions must be developed to make

prescription planting, rotations, and cover crops effective alternatives to maximum planting of transgenic corn across larger regions. The occurrence of pest insect populations (notably corn earworm and stink bugs) on wild host plants and the dispersal of these pests on a landscape scale are poorly understood, as are effects of differing sequences of rotation crops on the patterns and dispersion of major weed species.

Actions: ARS will:

Biology

- Determine biological, landscape, topographic, agronomic, and weather factors that impact the spatial distribution of natural enemies, as well as corn borer, rootworm and earworm abundance and damage among and within cornfields.
- Quantify the reliability of identified risk factors to predict the spatial distribution of pest pressure.
- Identify previous host plants of adult stink bugs found in corn.
- Characterize the dispersal of adult corn earworms and stink bugs at within-field and landscape spatial scales.
- Understand how cover crops affect weed dynamics.

Control

- Network with organic producers, identify key research needs, and evaluate solutions compatible with organic production practices.
- Examine the economic implications of herbicide-intensive production systems on arthropod diversity, insect management decisions, and the productivity of the entire cropping system relative to other weed management systems.
- Develop new control tactics that integrate appropriately with either organic or traditional corn management systems.

1. Environmental Stewardship

Importance: One of the long-term goals of ARS is to achieve sustainable agriculture that minimizes environmental impacts. Numerous services are provided by non-pest arthropods and plants within agroecosystems, and pest management practices that disrupt the functioning of these non-target species can be costly. There is a need to evaluate possible effects of new types of corn on non-target organisms compared with traditional forms of pest control so that growers are preserving natural ecosystem functions within their farmland while minimizing the impacts of pest species. Similarly, pesticides used in corn must be evaluated in terms of fate, transport, and non-target effects to preserve the high pest efficacy and low environmental impact that corn growers and the public have come to expect. To limit the frequency of resistance development, soil-applied herbicides now are recommended widely by extension and industry for use in glyphosate-resistant corn. These herbicides often include the older chloroacetamides (e.g., acetachlor) and triazines (atrazine) which commonly impact water supplies, and other newer residuals (e.g., flufenacet, isoxaflutole, mesotrione) about which we know much

less. These herbicides may have carry-over that influences choice of rotation crops and they may move off-site, either above ground via runoff or wind or below ground in shallow aquifers. Whatever the case, their fate and transport are dependent upon a myriad of biotic and abiotic factors.

Research Gaps: There is a fundamental need to establish better tests to evaluate non-target effects of new types of corn and corn pesticides. In particular, there is a need to develop limit-dose laboratory tests for representative beneficial insect species that can be reared easily in the laboratory. Also, there is a need to develop efficient field tests to assess impact of various corn systems on non-targets that provide valuable ecosystem services. Despite a general understanding of how synthetic chemicals degrade and move through an environment, many aspects of fate and transport remain unknown. Moreover, the ultimate long-term consequences to the environment of the presence of temporally-varying concentrations of differing herbicides still require analysis. Movements and metabolites of newer pesticides are studied rigorously prior to labeling by manufacturers, but once in widespread use in highly heterogeneous environments across large regions, unanticipated fates are to be expected and must be examined critically to minimize unintended consequences.

Actions: ARS will:

Control

- Develop laboratory-based tests to evaluate stressor compounds (usually proteins) produced by genetically engineered corn on various insects.
- Identify ecological pathways through which beneficial arthropods interact with genetically enhanced corn and corn ecosystems as a means to assess their exposure to potentially harmful aspects of these crops.
- Establish how genetically enhanced corn affects food webs compare with other pest management systems.

2. Developing and Using New Technologies

Importance: New technologies and techniques are needed to conserve the efficacy of insecticides and transgenic crops that have a narrow range of target pests. Laboratory studies show that many corn pests can evolve resistance to Bt proteins. New sources of native plant resistance traits to these pests can be stacked with Bt genes to delay the onset of resistance, or can be used alone to protect non-Bt refuge and organic corn. Development of resistance in corn insect pests to transgenic Bt proteins is the most recent example of an ongoing arms race in plant defense and insect herbivore counter-defense. Unraveling the molecular basis for these interactions is critical to devising sustainable pest management strategies. Microarray analysis and genetic mapping of pests will allow identification and potential manipulation of the genes in insects responsible for resistance and key life-history traits that can be exploited as weak links. Use of genetic markers for insect pests makes it possible to understand spatial patterns and the extent of insect pest movement over long distances, and the ability to develop good markers will increase as DNA sequencing projects are conducted on ESTs or entire insect genomes.

Weed control in corn is dominated by application of synthetic herbicides, an activity that has been enormously successful. Even organic producers can appreciate the efficacies of these products, which is why there is an incipient market for organic herbicides. Many natural plant and microbial chemicals have phytotoxic activities. Some of these chemicals can be used in their original forms as herbicides, or they can be used as templates and possibly modified for enhanced effectiveness.

Research Gaps: New plant resistance traits are needed to enhance Bt-corn IRM, and as an alternative control option for non-Bt corn. Although a number of corn inbred lines and partial inbred lines are known to confer resistance against single insect species, few have been assessed for native resistance to multiple key insect pests at multiple growth stages of the plant. Additional low-input pest control technologies and techniques are critical as an alternative or as a complement to current pest control technology, especially for organic and non-Bt refuge corn production. Though difficult to study, we need a much better understanding of long distance insect movement, which is necessary for predicting pest population dynamics. Subgroups of insect pests that prefer different host plants, or interact with host plants in different ways, often exist without our knowledge based on monitoring data. This hinders efforts to accurately assess the threat posed to a crop at a given time and place. Little or no microarray data are available for most corn insect pests and this data will be critical to deciphering the molecular mechanisms of interaction between pests and corn, and the genes that are involved. This effort will require much more DNA sequence data, genetic mapping, and gene discovery for the pests than are currently available.

Only a few of the vast array of natural plant and microbial products that are phytotoxic have been identified and isolated, with one of the most recent highly-active moieties being the simple nonprotein amino acid, m-tyrosine, from fescue grasses. For most of these chemicals their identity and associated biochemistry and molecular biology are entirely unknown, as are their potential roles in plant defense and crop protection.

Actions: ARS will:

Control

- Characterize newly-discovered native plant resistance traits of corn earworm, southwestern corn borer, and corn rootworm by understanding their genetic control and determining chemical/biochemical, physiological and/or morphological bases of resistance.
- Identify and characterize the genes for these traits at the molecular level for genetic enhancement in corn and for genetic engineering of alternative crops.
- Screen and develop corn germplasm that confers root-, leaf- and ear-feeding insect resistance at multiple locations from Midwest, Mid South, and South Atlantic Regions.

- Develop and use molecular genetic markers to characterize gene flow, and therefore dispersal patterns, of insect pests of corn at different spatial scales.
- Use genetic markers to reveal potential host races or other distinct races or variants.
- Develop and use molecular markers to construct genetic linkage maps for corn pests.
- Understand the dynamic nature of the molecular basis for plant-insect interactions in corn.
- Derive and test natural products from plants and microbes that have potential as natural pesticides in corn, other crops, and elsewhere.

3. Emerging Pest Problems and Issues

Importance: Corn management system changes have increased the frequency of emerging pest issues, and expanded commerce has increased the introduction rate and spread of invasive species. Western bean cutworms are increasing their geographic range to the eastern portion of the Corn Belt. Most varieties of Bt-corn do not adequately control this pest. Western bean cutworm may be evolving resistance to the few varieties that do partially control this insect, threatening growers' investments in the Bt-technologies. Reduced use of insecticides on Bt-cotton and -corn has resulted in increases in brown, green, and southern green stink bug populations, which contribute to an increase of corn ear damage and associated ear rot and aflatoxin/fumonisin contaminations. Further, a new invasive moth species called the chocolate milkworm infests high numbers of ears on pre-harvest corn in Louisiana and Georgia. In addition, aflatoxin reduction research is critically needed because ethanol production from corn will significantly increase aflatoxin levels as high as three times in the dry distiller grains (DDGs).

New management systems in corn and associated rotational crops have not only selected for glyphosate-resistant populations of previously common weed species, but also for species that are naturally tolerant to glyphosate. Examples of these “species shifts” include Benghal dayflower in the southeastern United States and Asiatic dayflower in the southwestern and central Corn Belt. Furthermore, new introductions, such as apple-of-Peru, may pose additional problems for weed management in corn. Not only are control procedures poorly understood for these species, but their effects on crops, basic biology and ecology, and propensity as hosts for diseases and insects are largely unknown.

Research Gaps: The tendency of western bean cutworm to spread into new geographic areas and its potential to evolve resistance to Bt-corn need to be studied. Little is known about the population dynamics and economic injury levels of the stink bug complex and chocolate milkworm in southern corn production regions. Ecological interactions among these insect pest populations, the severity of all key ear- and kernel-feeding insect damage, and ear rot infection rate, as well as mycotoxin (aflatoxin and fumonisin) contamination levels in pre-harvest corn is not well defined. Also, the influence of pre-

and post-harvest insect pest damage on aflatoxin levels in corn grains is not well understood.

New weed species not only enter the United States regularly, but naturalized and native weeds evolve and adapt to new conditions. For instance, the evolution of resistance to glyphosate in giant ragweed populations was mentioned earlier, but equally important is the evolution of other traits important to management. An excellent example involves delayed seedling emergence in giant ragweed. Giant ragweed traditionally was amongst the earliest of summer annual species to emerge in spring, which allowed for easy control through seed bed preparation. With the advent of corn hybrids tolerant to early planting, populations of giant ragweed with delayed emergence now are common in Ohio and Indiana. Nearly identical behavior was observed recently with kochia in the northern Great Plains. Delayed emergence is but one of many weed traits that critically affect management decisions. Broadscale research and understanding of these characteristics will be required to permit better management of these types of species in the future.

Actions: ARS will:

Biology

- Conduct flight mill studies and population genetic research to assess movement and gene flow in the western bean cutworm.
- Examine stink bug and chocolate milkworm biology, population dynamics and economic injury levels.
- Conduct detailed research to examine ecological interactions between the severity of ear- and kernel-feeding insect damage and ear rot infection rate, as well as mycotoxin (aflatoxin and fumonisin) contamination levels in pre-harvest corn.
- Conduct flight mill studies to assess dispersal activity of adult stink bugs.

Control

- Selection experiments and resistance monitoring research will assess the risk of evolution for resistance to Cry1F-expressing corn in the Western bean cutworm.

***Anticipated Products*:**

- Information on specific genes and gene-products involved in insect resistance to genetically enhanced corn.
- Identification of plant traits that might be used to develop pest-resistant plants.
- Development of plants with pest resistance.
- Improved pest sampling and detection methods.
- Diagnostic markers to distinguish races or variants of pest species that attack corn.
- Markers for determining origin of migrant pests and characterizing their movement.

- Production of linkage maps that can be used for locating genes of interest, such as resistance genes or novel targets for control.
- Procedures using predictive criteria to guide grower decisions on where it will be cost-effective to plant transgenic corn among and within fields on a farm.
- Anticipate patterns and speed of resistance spread through pest populations.
- Increased knowledge of pest biology, ecology, behavior, genetics, and biological control agents, and of plant traits conferring pest resistance.
- Increased knowledge of the genomics, and basic biology and ecology of biological control agents.
- Improved understanding of how weeds respond to agroecosystem modifications, such as but not limited to cover crops and rotations.
- New weed control products appropriate for organic and conventional cropping systems.
- Novel weed control tactics appropriate for organic and conventional cropping systems.

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

- Strategies for improved IPM of corn insect pests and weeds.
- Reductions in crop losses due to insect pests of corn and the plant diseases they transmit.
- Reductions in expenditures to manage insect pests and weeds.
- IPM tactics that are ecologically sound.
- Gains in farmer profitability could be made if transgenic corn targeting pests like corn borers and rootworms could be planted only where needed.
- Fewer acres planted to transgenic corn will reduce selection pressure on the insect pests, and slow development of resistance.
- Provides critical information for designing effective resistance mitigation strategies.
- Development of pest-resistant corn lines that can be used as low-input alternatives to transgenic Bt-corn in refuges or organic production.
- Development of Bt-corn with stacked native resistance to slow evolution of resistant populations of insects.
- Ability to monitor spread of races or variants into new regions.
- Ability to better assess real-time threat to corn from migrant pests, including races with different behaviors and host preferences.
- Recommendations for appropriate rotation frequencies of both crops and herbicides to stymie evolution of weed resistance and shifts to naturally tolerant weed species, and cause a general reduction in weed populations.
- Enhanced arsenal of weed control tactics appropriate for organic and conventional corn.

USDA ARS Resources:

- Areawide Pest Management Research Unit, College Station, Texas
- Corn Insects and Crop Genetics Resarch Unit, Ames, Iowa
- Crop Protection and Management Research Unit, Tifton, Georgia
- Insect Genetics and Biochemistry Research Unit, Fargo, North Dakota
- Invasive Weed Management Research Unit, Urbana, Illinois
- Natural Products Research Unit, Oxford, Mississippi
- New Crops and Processing Technology Research Unit, Peoria, Illinois
- North Central Agricultural Research Laboratory, Brookings, South Dakota
- North Central Soil Conservation Research Laboratory, Morris, Minnesota
- Northern Plains Agricultural Research Laboratory, Sidney, Montana
- Plant Genetics Research Unit, Columbia, Missouri
- Soil and Water Management Research Unit, St Paul, Minnesota
- Southern Insect Management Research Unit, Stoneville, Mississippi
- Southern Weed Science Research Unit, Stoneville, Mississippi
- Sustainable Agricultural Systems Laboratory, Beltsville, Maryland
- Water Management Research Unit, Fort Collins, Colorado