Midsouth Entomologist 7: 89-98
ISSN: 1936-6019
www.midsouthentomologist.org.msstate.edu

Importance of Tarnished Plant Bug as a United States Department of Agriculture Agricultural Research Service Research Priority

Report

R. G. Luttrell and E. G. King

US Department of Agriculture, Agricultural Research Service. Stoneville, MS 38776

Corresponding author email: Randy.Luttrell@ARS.USDA.GOV

Received*: 24-I-2014 Accepted: 04-III-2014*

Abstract: Environmental and economic management of tarnished plant bug (TPB) (*Lygus lineolaris*) on cotton has been an area of continuous study by USDA scientists in Stoneville, Mississippi since the 1960s. Maintaining economically viable cotton production has required dynamic research information and increasingly sophisticated management approaches for this native insect that feeds on many cultivated and wild host plants. In close collaboration with university partners, USDA scientists in Stoneville accumulated a wealth of scientific information on TPB that routinely addressed changing management challenges and continues to provide benchmark information needed to sustain economic cotton production in the Mississippi Delta. More than 60 scientific journal articles have been published on TPB by Stoneville scientists, and hundreds of conference proceedings and scientific presentations have been made by USDA scientists at various scientific and production conferences. Research by Stoneville USDA scientists influenced a shift in traditional integrated pest management (IPM) approaches on cotton by illustrating the impact of the insect on crop maturity and profitability. This collective information is a major fraction of the total known information about this insect pest, especially as it relates to cotton. In this paper, the major research accomplishments of USDA scientists at Stoneville, Mississippi studying the biology, ecology and control of TPB on cotton are summarized. Future scientists will build increasingly sophisticated and effective pest management systems using the fundamental information accumulated in these USDA studies.

Keywords: tarnished plant bug, cotton insect management, USDA research

Introduction

USDA scientists at Stoneville, Mississippi have been studying the impact of tarnished plant bug (TPB) (*Lygus lineolaris*) on cotton and exploring methods of controlling the pest for more than 50 years. Prior to successful eradication of the boll weevil (*Anthonomus grandis grandis)* and deployment of transgenic Bt cottons for control of tobacco budworm (*Heliothis virescens*) and bollworm (*Helicoverpa zea*), TPB was a routine and troubling pest in the Mississippi Delta. Direct damage was not as evident as the massive crop losses associated with boll weevil and tobacco budworm (Parencia and Martin 1989, but impacts on crop maturity and profitability were significant and evident to Delta producers. Recent changes in management options and crop structure across the Delta landscape have had dramatic impacts on pest abundance and importance. For the past few years, TPB has been ranked by the National Cotton Council (M. Williams, Mississippi State University http://www.entomology.msstate.edu/resources/cottoncrop.asap) as the single most important insect pest of cotton in the U.S. In Mississippi and surrounding states, control costs have approached or exceeded $100 per acre.

TPB management and associations with boll weevil and tobacco budworm control options shaped fundamental philosophies of cotton insect control in the Mississippi Delta. Federal-supported research scientists have provided important contributions to evolution of cotton insect management since 1934 when the Delta Cotton Insect Investigations Laboratory, Division of Cotton Insects, Bureau of Entomology and Plant Quarantine, USDA was created in Stoneville, Mississippi and E. W. Dunnam was stationed at the Delta Branch Research Station of Mississippi State University. The research partnership between the USDA and Mississippi State University has been a consistent strength of these contributions, one that is valued locally and admired worldwide. While the scientific contributions impact a wide diversity of agricultural issues, the historical example of cotton pest management and TPB provide a unique example of the commitment of USDA to solving agricultural problems. It is also a reminder of the ongoing need for agricultural scientists to work at the interface of science and practical application to commercial agriculture. In this overview of USDA research, previous accomplishments of USDA entomologists working on TPB in the Mississippi Delta are summarized. Future researchers are encouraged to expand these foundation studies and develop more quantitative characterizations of TPB biology, ecology and management options.

Previous Research

USDA research on the TPB at Stoneville, Mississippi began in the 1960s when Arden Scales conducted a number of studies to understand the insect and its impact on cotton. Scales (1968) found that female TPB attract males, and Scales (1972) reported parasites of the tarnished plant bug in the Delta. These early observations were an important start to more elaborate studies that influenced overall approaches to cotton pest management and current cotton production practices. During the 1960s and 1970s, TPB was considered to be a secondary pest of cotton. Accepted integrated pest management (IPM) practices strongly advocated delaying insecticide use to preserve beneficial species and avoid unnecessary disruption of natural control of tobacco budworm and bollworm. Early-season impacts of fruit-feeding insects were discounted on the basis of potential plant compensation and a long growing season. The risk of triggering outbreaks of insecticide-resistant tobacco budworm limited interest in controlling early-season populations of TPB. Research at Stoneville, Mississippi questioned some of these widely accepted approached to cotton IPM. Scales and Furr (1968) conducted experiments that associated deformed cotton plants with early-season TPB infestations. Contemporary work by Marian Laster, a long-time entomologist at the Delta Branch Research Station and a valued USDA collaborator, reported cotton damage by TPB (Laster and Davis 1967) and associated damage with potential late-season boll rot problems (Bagga and Laster 1968). Scales and Stadelbacher (1972) and Scales and Hacskaylo (1974) recognized that different cotton varieties respond differently to TPB infestations resulting in different levels of damage. They began studies to compare the performance of different cottons under heavy infestations of TPB. Tommy Cleveland, a USDA entomologist working in Tallulah, Louisiana began studies on insecticidal control of TPB in the 1960s (Cleveland and Smith 1968). He later transferred to Stoneville, Mississippi and continued work on TPB.

Research on host plant resistance intensified in the 1970s when Bill Meredith and a number of collaborating plant breeders and entomologists began investigations of host plant resistance traits in cotton. Over the next few decades, the research would result in commercial cottons with early-maturity and nectariless traits for TPB management. These benchmark studies greatly impacted the cotton industry and illustrated a capacity of USDA research to address important grower problems. Hanney et al. (1977) and Laster and Meredith (1974) conducted field studies demonstrating the impacts of different cottons on cotton injury and yield loss from TPB. Meredith and Schuster (1979) explored the impact of cotton pubescence on TPB damage. Collectively, the work of Laster, Meredith and colleagues began to reveal the impact of early-season damage by TPB on Delta cotton production. The demonstrated reduction in TPB densities on nectariless cotton remains as a practical alternative to chemical control of the pest.

The 1980s were a time of greatly expanded USDA research on TPB in the Mississippi Delta. Gordon Snodgrass began his career as an Agricultural Research Service (ARS) scientist working with Jimmy Smith and William Scott. Their collaborative work over the next two decades further highlighted the impact of TPB on Delta cotton production and helped shift traditional IPM approaches away from avoiding early-season insecticide use and preserving natural control to optimizing early crop maturity and avoiding late-season pest problems and harvest hazards. These changes were influenced by evolving insect control technologies. Pyrethroid insecticides introduced in the 1970s were widely deployed and provided outstanding control of lepidopteran pests until tobacco budworm populations became resistant in the late 1980s (Naranjo and Luttrell 2009). Research on biological control of crop pests, opportunities for expansion of IPM programs, and profitability of cotton encouraged scientific investments in new approaches to cotton insect pest management. Research programs at Stoneville, Mississippi were at the forefront of these efforts. Expanded research on host plant resistance included additional studies on the nectariless trait (Bailey et al. 1980, 1984). Research also began to focus on management systems where plant resistance was visualized as a component of a total management system. Bailey and Cathy (1985) studied the impact of chlordimeform, an ovicide for lepidopteran pests, on TPB nymphs. Bailey et al. (1980) examined different host plant resistance traits and different chemical control strategies in combination. Baker et al. (1985) and Laster et al. (1984) explored impacts of herbicides on TPB populations. Parrot et al. (1985) and Scott et al. (1985) demonstrated significant impacts of aldicarb applications at planting on subsequent populations of TPB in squaring cotton. Scott et al. (1986) reported dramatic impacts of early-season applications of insecticides on TPB control, crop maturity and yield. These studies demonstrated dramatic impacts of TPB on cotton yield, delayed crop maturity and profitability. These data combined with work of Mississippi State University economists studying crop maturity increased awareness of TPB as a pest of cotton and the magnitude of the impact of delayed crop maturity (Parvin et al. 1987, Parvin 1992). Philosophies of delaying insecticide sprays to preserve natural control were challenged because of perceived economic benefits associated with TPB in these studies and automatic applications of insecticides were advocated as a standard approach to managing early-season pests of cotton and insuring early crop maturity.

To some extent the linkage between TPBs and crop maturity was overstated with Parvin’s crop maturity models. Sheng and Hopper (1988) reported that the magnitude of the effect of early-season insects on cotton maturity would have to be excessively large to account for the magnitude of economic effect suggested by Parvin et al. (1987) and Parvin (1992). Additional studies further investigated suggested relationships between crop maturity, plant compensation and insect control and generally confirmed the over-estimate of impact and the dynamic relationships among the factors modeled. Sheng et al (1988) used ethephon to remove early season squares and demonstrated that yield could actually be increased with removal of early season fruit. While the debate over TPBs and approaches to early season cotton insect control continues to this day, concepts of crop maturity and understanding of managing fruit retention became firmly established in Delta cotton production. The magnitude of the impacts and implications to early-season insects may have been overstated in some studies, but general importance of early crop maturity and avoiding harvest hazards were widely accepted. Later studies helped refine the magnitude of plant compensation and importance of managing cotton fruit retention for desired crop maturity. King et al. (1990, 1992) suggested use of ethephon to manage crop maturity and avoid late-season problems with boll weevil. Jenkins et al. (1990a, 1990b) produced cotton maps that visually associated different fruiting positions with varying economic value. Collectively, this information improved understanding of crop maturity and potential impact of TPB on the crop. Subsequent crop management tools, like the COTMAN program developed in Arkansas and deployed across the U.S. Cotton Belt (http://cotman.org/), further refined the relationship between fruit retention and crop maturity and assisted growers with optimization of crop management practices.

Chemical control was not the only emphasis of TPB control in the 1980s. Gordon Snodgrass, working with Jimmy Smith and William Scott, made major contributions to understanding of TPB biology and ecology. Their reference on host sequence (Snodgrass et al. 1984) is one of the most highly cited TPB papers in the scientific literature. It added significant detail applicable to area-wide management and expanded the previous work of Cleveland (1982). Young (1986) also published a list of TPB host plants, and Young and Lockley (1986) and Young and Welbourn (1987) described predation of TPBs by spiders.

Snodgrass' work provided a foundation for expanded area-wide and cultural management of TPB over the next three decades.

Cotton insect management in the early-1990s was impacted dramatically by insecticide-resistant populations of tobacco budworm. USDA scientists were involved in a number of creative area-wide efforts to manage tobacco budworm during this period, including augmentative release of parasitoids, area-wide destruction of early-season host plants, autocidal control with a sterile hybrid, and area-wide spraying with biological insecticides. Complexity of cotton pest management further increased with expanding boll weevil eradication efforts that relied on area-wide sprays of malathion and introduction of transgenic Bt cottons that promised almost complete protection of the crop from damage by previously uncontrolled populations of tobacco budworm. During this period of rapid technology change, TPB problems on cotton increased and insecticide resistance was documented as a problem in this highly polyphagous pest species raising a number of ecological questions about the impact of broad-spectrum insecticides in cotton. In recognition of a need to accurately assess population growth of TPB populations in cotton, the target crop of most insecticide use in the Delta, Snodgrass (1993) studied sampling efficiency of the drop cloth and published relationships between drop cloth samples of TPB nymphs and estimated absolute densities. A few years later, Snodgrass (1996a) reported insecticide resistance in TPB using a glass vial assay (Snodgrass 1996b) similar to procedures developed to study pyrethroid resistance in tobacco budworm adults (Naranjo and Luttrell 2009). Recognition that TPB, a highly polyphagous pest feeding on many non-crop hosts, would develop resistant populations to insecticides targeted for crops raised a number of spatial and temporal questions about populations of the bug across the Mississippi Delta. Snodgrass (1998) studied the distribution of TPBs in cotton, partially because ineffective control was attributed to inability to deposit insecticides to lower locations in the plant canopy where TPBs can escape exposure to insecticides. Documentation of insecticide resistance and availability of a monitoring tool to measure resistance levels across time and space provided a foundation for future research that expanded to molecular studies of resistance mechanisms and current studies of population substructure in this mobile pest species. Bt cotton varieties were commercially introduced for lepidopteran control in 1996, about the same time as the documentation of insecticide resistance in TPB and the expansion of boll weevil eradication into the Mississippi Delta. Hardee and Bryan (1997) studied potential impact of Bt cotton on TPB control, a complex question that continues to be a focal point of field research. Snodgrass and Stadelbacher (1994) studied impact of mowing and herbicide control of *Geranium dissectum* for tobacco budworm suppression on beneficial arthropods and TPB. Results encouraged future area-wide management programs where broad-leaf weeds were removed from field borders and ditches to eliminate early-season hosts of TPB and reduce densities colonizing cotton.

Building on research results from the previous four decades, Stoneville USDA scientists refocused TPB research in the first decade of the 21st century to better understand ecological and genetic factors impacting increased pest status and problems with control of TPB in cotton. Nordlund and Hardee (2000), two research leaders with the USDA ARS in Stoneville, organized a symposium to summarize current knowledge of Lygus management as a basis for future research and management strategies. This symposium included federal and university scientists across the U.S. Cotton Belt. A majority of the summative papers were authored by federal and university scientists working in Mississippi and surrounding states. During this period, serious efforts to implement area-wide management systems for TPB were initiated across the Delta region with close cooperation between USDA and university entomologists. The number of USDA scientists at Stoneville studying TPB increased with expertise ranging from field-level management to molecular exploration of resistance mechanisms and population structure. Snodgrass (2002) reported a red eye mutant strain of TPB from field collections. This population trait continues to be a valued tool in studying population traits. Snodgrass (2003) described a reproductive diapause in TPB that provided an improved understanding of genetic and ecological factors governing population dynamics of the pest, especially overwintering populations concentrated on wild hosts.

Experience gained from area-wide programs to suppression of tobacco budworm populations and the growing base of ecological information about TPB provided essential strategic and logistical tools necessary to implement innovative management systems for TPB on an area-wide basis. Snodgrass et al. (2005) provided quantitative estimates of TPB numbers in ditches and field margins prior to cotton squaring and movement of bugs from wild hosts to cotton. Snodgrass et al. (2006) measured suppression of TPB numbers in cotton when wild host plants were mowed or killed with herbicides in the spring. Abel et al. (2007) summarized economic and ecological impact of area-wide management effort. Densities of TPBs and insecticide treatments were reduced ~50% in areas with early-season management of wild hosts. Because of a growing problem with insecticide resistance to pyrethroids (Snodgrass and Scott 2000) and documentation of populations resistant to malathion (Snodgrass and Scott 2003),insecticide used to eradicate boll weevil, the cultural management option received attention and interest from Delta farmers. Snodgrass et al. (2009) reported resistance to acephate, an important organophosphate insecticide with systemic activity and widespread use against early-season insects which further heightened interest in alternative approaches to TPB management. As a result, the host destruction program expanded to area-wide studies in Louisiana, Arkansas, and Tennessee, as well as ongoing studies in both the Delta and Hill regions of Mississippi. (Cook et al. 2008, Lorenz et al. 2006 , Stewart et al. 2006).

The search for creative, alternative approaches to TPB management further expanded into a search for biological agents in the 21st century. Livy Williams began a search for potential parasitoids to be used in a classical biological control program. Zhu and Williams (2002) used a molecular approach to identify egg parasitoids of TPB. Jarrod Leland, an insect pathologist, initiated a program to identify potential microbial control agents for TPB. Leland and Snodgrass (2004) surveyed natural populations of TPB in the Mississippi Delta and reported the prevalence of naturally occurring fungal pathogens. Leland (2005) isolated several strains of the entomopathogenic fungus, *Beauveria bassiana*, with activity against TPB. One of the strains, currently recognized as NI8, has 10-fold more activity against TPBs in laboratory assays than commercially available strains (Leland et al. 2005). Research continues to this day on developing strategic management options for TPB for NI8, especially options for treating diapausing adults in overwintering wild host plants (Snodgrass et al. 2012). Leland and Behle (2005) worked with lignin as a possible UV-protectant to extend life and enhance activity of the fungus against TPB on different host plants. Leland et al. (2005) reviewed procedures for selecting different strains of *B. bassiana* for TPB. This work gained national recognition and involved collaborative research with USDA entomologists in California studying alternative controls for *Lygus hesperus*, a closely related species attacking cotton and other crops in the western U.S.

Molecular biology became a routine component of entomological research in the 21st century. Zhu and Snodgrass (2003), Zhu et al. (2003) and Zhu et al. (2004) reported that metabolic mechanisms (esterase enzymes and cytochrome P450 enzymes) were responsible for insecticide resistance in TPBs in the Mississippi Delta. Zhu et al. (2003) conducted molecular studies on proteinase activity in salivary glands of TPB. Allen (2007) and Allen and Mertens (2008) developed sequence tags and used molecular cloning techniques to identify potential new molecular targets for TPB control. Perera et al. (2007) described eight polymorphic microsatellite markers for studying TPB population structure. This initial molecular work provides a foundation for expanded molecular examinations of field populations, gene flow and insecticide resistance evolution in this polyphagous insect pest.

Current and Future Research Opportunities

Since 2010, research emphasis on TPB has continued to build on expanding opportunities to understand population genetics, pest dispersal and opportunities to manage populations of TPBs. The insect's ability to evolve resistance is a major threat to sustainable crop production systems and an underlying justification for expanded USDA research on TPB population genetics and field ecology. Abel et al. (2010) confirmed that corn is a viable reproductive host for TPB and a common food source for adults transiting from wild hosts in April and early-May to squaring cotton in mid-June. Snodgrass et al. (2010) reported a similar ecological relationship between early-season soybean and TPBs moving from wild hosts to cotton. Indeterminate soybeans are attractive to adults, and large numbers of immature TPBs can be found on early-season soybeans that flower in early June. Changing crop structure in the Mississippi Delta altered the crop and wild host relationships previously explored for area-wide management systems. Future management options will be impacted by reduced acreages of cotton grown in regions with expanded acres of corn and early-season soybean.

Ugine (2011, 2012) developed elaborate temperature-life table models for TPB that will be useful in modeling population growth of insects exposed to *B. bassiana* or other biological control agents. Perera et al. (2012) reported a detailed molecular description of a single-stranded RNA-virus isolated from TPBs in the Mississippi Delta. Incorporating new control agents into management systems requires a quantitative knowledge of insect dispersal from host plant to host plant. Ryan Jackson and colleagues developed elemental analysis techniques to track TPB dispersal from different cultivated and wild hosts. This research is based on C and N isotopes and the elemental composition of insect wings. We currently have the capacity to differentiate different natal hosts of TPBs captured on cotton or other crops. Bugs developing as immature on C3 plants (many broadleaf weeds, soybean, cotton) can be distinguished from those developing on C4 plants (corn, pigweed). Using N isotopes, Jackson and colleagues can differentiate TPBs that developed as nymphs on corn from those that developed as nymphs on pigweed.

Several new insecticide classes are now available for TPB including novaluron, an insect growth regulator, and sulfoxaflur, a new insecticide that blocks nicotinergic receptors in the insect's central nervous system. Both have activity against TPBs with known resistance to other modes of action. Ongoing studies to track insecticide resistance continue but with more elaborate molecular and ecological data and additional studies on new insecticide groups. A number of other papers in this special issue of Midsouth Entomologist describe progress in understanding population genetics, expanding microbial control options, and synthesizing the wealth of information collected by previous USDA scientists over the last 50 years.

The story of TPB research at Stoneville, Mississippi illustrates the commitment of the USDA Agricultural Research Service to long-term solutions for farmer problems. The career of several scientists especially that of Gordon Snodgrass, provides an example of the benefits of long-term investment in ecological research. Future management systems will increasingly rely on foundation studies of ecological and genetic traits of pest species and an ability to assimilate contemporary information into management options forged from previous empirical research.

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