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Report

Highlights of 30 Years of Research on TPB in the Mississippi Delta

Snodgrass, G. L.

USDA-ARS, Southern Insect Management Research Unit, 141 Experiment Station Road, Stoneville, MS 38776

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Abstract: The tarnished plant bug (TPB), *Lygus lineolaris* (Palisot de Beauvois), is a mirid species indigenous to North America. It is extremely well adapted to its habitat in the mid-South, and can feed and reproduce on most plant species in the mid-South when they bloom or have developing fruit. TPB nymphs produce adults in diapause on weed hosts in response to decreasing day lengths during the fall (beginning in September). Diapausing adults can overwinter on weed hosts or in plant debris, and adults overwintering in plant debris break diapause during January using an internal clock. Diapausing adults on weed hosts can break diapause at any time (despite the diapause-maintaining day lengths) in response to a good food source (weed hosts) and warm temperatures. This allows them to become reproductive and increase the size of the overwintering generation or produce an earlier F1 generation. The pest status of the TPB has changed from that of a minor pest of cotton in the mid-South thirty years ago to being the main pest of cotton at the present time. This increase in pest status was partly due to several agricultural and technological changes. These changes included boll weevil, *Anthonomous grandis* (Boheman), eradication and the use of transgenic cotton to control lepidopterous pests. Both of these changes decreased insecticide use in cotton which allowed TPB to increase in number. A large increase in early soybean and maize acreage (which are both TPB reproductive hosts) with a corresponding decrease in cotton acreage over the past ten years also favored increased numbers of TPB in cotton. Most importantly, many TPB populations in the mid-South have insecticide resistance to carbamate, organophosphate, and pyrethroid insecticides used for their control. This has increased control costs to growers and decreased yields. Several non-insecticidal control measures have been researched in an effort to provide additional control of TPB. These include cultural control, parasitoids, nectariless cotton, and mycoinsecticides. Most of these control measures need additional research and development before they could be combined with insecticides in an integrated control program for TPB in cotton.

Keywords: Tarnished plant bug, Mississippi Delta

Introduction

The tarnished plant bug (TPB), Lygus lineolaris (Palisot de Beauvois), is currently the number one pest of cotton, *Gossypium hirsutum* L., grown in the mid-South (Williams 2013). Its rise to this pest status was mainly the result of its development of resistance to insecticides almost exclusively used for its control in cotton. Other causes that contributed to its increased pest status are discussed in this manuscript. The basic biology along with several non-insecticidal control methods that could be used in the development of an integrated control program for TPB in cotton have been studied, but data needed to combine these control measures with insecticide use are incomplete. Results from research on the basic biology of the TPB along with those from monitoring insecticide resistance and the development of non-insecticidal control measures are presented in this manuscript.

Results

Wild hosts. The TPB is one of 107 species of mirids in 47 genera found in the mid-South (Snodgrass et al. 1984a). One other species of Lygus (*Lygus plagiatus* Uhler) is present on giant ragweed, *Ambrosia trifida* L., but it is not a pest of crops. TPB can be found on 169 host plant species in 36 families in the mid-South with the family Asteraceae having the largest number of hosts (Snodgrass et al. 1983, Snodgrass et al 1984b). The highest populations of TPB on wild hosts in the mid-South are found during May and June and in September and October. (Snodgrass et al. 1984b). During these two time periods, the highest numbers of wild host species are also available. During the summer months of June and July, many of the host species found in May and June senesce and the number of wild hosts available declines. This is one reason for TPB migration into cotton which becomes the most abundant host available in July (Snodgrass et al. 1984b). In July and August, the best wild hosts (highest TPB populations) are smartweed, *Polygonum spp.*, marestail, *Conyza canadensis* (L.) Cronquist, ragweed, *Ambrosia spp.*, and pigweed, *Amaranthus spp.* In the fall, the best hosts are smartweed, ragweed, pigweed, tall goldenrod, *Solidago altissima* L., and aster, *Symphyotrichum spp.* , while henbit, *Lamium amplexicaule* L., and sheperd's purse, *Capsella bursa-pastoris* (L.) Medicus are the best winter hosts. In the spring, the best hosts are curly dock, *Rumex crispus* L., vetch, *Vicia* spp., shepherd's purse, primrose, *Oenothera* spp., fleabane, *Erigeron* spp., and plains coreopsis, *Coreopsis tinctoria* Nuttall (Snodgrass et al. 1984b). The number of species of wild hosts in the mid-South has probably not changed much over the past 30-year-period. However, the abundance of two very good wild hosts, marestail and Palmer amaranth, *Amaranthus palmeri* S. Wats., has probably increased in recent years because of their development of resistance to glyphosate (Roundup) which is used extensively for weed control in the mid-South.

Crop Hosts. The main changes in crop hosts in the mid-South have occurred over the past ten years. The number of hectares of cotton grown in Mississippi has declined from 497,976 ha planted in 2006 to 121,458 ha planted in 2013 (NASS 2013). Cotton acreage has been replaced by maize, *Zea mays* L., (348,178 ha planted in 2013) and soybeans, *Glycine max* L., (813,765 ha planted in 2013). TPB usually do not utilize a host for reproduction unless flower buds or blooms are present (Snodgrass et al. 1984b). Early soybeans bloom during May and are utilized by TPB as a reproductive host (as many as 8751 nymphs per ha) to produce one new generation (Snodgrass et al. 2010). TPB migrate from early soybeans when they finish blooming during June and can move to wild hosts or maize which begins tasseling during June. One new generation can be produced on maize where as many as 29,600 nymphs/ha have been estimated to be present during tasseling and the R1-R3 ear growth stages (Abel et al. 2010). Adults produced in maize can move to cotton in late June and July (Kumar and Musser 2009, Jackson et al. 2012). During July and August there is a decline in the number of wild host plant species available (Snodgrass et al. 1984b) and cotton is the most abundant TPB host available. The decline in cotton acreage along with the large amount of maize grown in the mid-South has made the TPB an abundant and consistent pest of cotton especially during July and August. In most years, cotton growers must treat their fields with multiple insecticide applications. Many growers have found that the profit from raising cotton is less than could be obtained by growing maize or soybeans. The TPB is one cause for the profit difference and the reduction of cotton acreage in the mid-South.

Laboratory Rearing. The TPB develops through five nymphal instars and the developmental times on the same host for the instars vary with temperature. All five instars require an average of 14.9, 19.7, and 31.5 d when reared on green bean pods, *Phaseolus vulgaris* L., at 30, 25 and 20^{o} C, respectively (Ridgway and Gyrisco 1960). The average time required for egg hatch was 14.7, 7.6, and 6.7 d for eggs held at 20, 25, and 30^{0}C, respectively. Adults have a preoviposition period of 7.0 to 25.4 d at temperatures of 16-25^{0}C (Khattat and Stewart 1977). Females lived longer than males when reared in the laboratory on potato, *Solanum tuberosum* L., sprouts, averaging 57.4 and 40.1 d, respectively, at temperatures of 16-28^{0}C . In addition to green bean pods and sprouting potatoes (Khattat and Stewart 1977, Slaymaker and Tugwell 1984), TPB can be reared in the laboratory on lettuce, *Lactuca sativa* L. (Stevenson and Roberts 1973), broccoli, *Brassica oleracea* L. var. *botrytis* L., (Snodgrass and McWilliams 1992), and artificial diet (Cohen 2000). The quality of the host plant can affect developmental time. Fleischer and Gaylor (1988) found that the mean generation time for TPB on annual fleabane, *Erigeron annuus* (L.) Persoon was 30.1 d as compared to 43.3 d for cotton.

Reproductive Diapause. The TPB overwinters as unmated diapausing adult in North America. In the mid-South, the critical photoperiod for diapause induction was found to be 12.5:11.5 (L: D) h or 12 September (Snodgrass 2003). At this day length about 50% of the nymphs developing in the field become diapausing adults. Diapausing adults can overwinter in plant debris, but they are also present on fall and winter host plants until the hosts senesce or are killed by cold. A small part of the population found on wild hosts in October and November break diapause, reproduce, and increase the number of overwintering adults (Snodgrass et al. 2012). This increase can occur as long as there is not an early killing frost. In most Decembers in the mid-South, the temperature is warm enough for two species of wild hosts, shepherd's purse and henbit, to grow and bloom. Adults that feed on these hosts have a rich food source along with temperatures warm enough for the wild hosts to grow and bloom. These adults break diapause during December (Snodgrass 2003) and in January of warm winters nymphs can be found with F1 adults produced by mid-March. Laboratory tests showed that good food and warm temperatures can be used to break TPB from diapause under a diapause-maintaining day length of 10 h which is about the day length found in the mid-South in December (Snodgrass et al. 2012). For most temperate-zone insect species with an overwintering diapause, no specific diapause-terminating stimulus has been identified (Tauber et al. 1986). Part of the overwintering TPB population is found in plant debris. These adults always break diapause during January regardless of the temperature and lack of food. Laboratory tests showed that they emerge from diapause using an internal clock (Snodgrass et al. 2012). Adult TPB that overwinter in plant debris produce the F1 generation in most years by mid-April. In winters cold enough to kill or stunt winter hosts, all of the overwintering population is found in plant debris. The ability of diapausing TPB to break diapause in response to food and temperature stimuli allows this insect to utilize favorable weather and increase its numbers. Early emergence from diapause is a risk since a hard freeze in the fall or in January or February could kill the host plant and prevent nymphs or eggs from developing. Diapausing adults from an area (Springfield, ILL) in which no winter hosts are available also have the ability to break diapause in response to food and temperature stimuli under a diapause-maintaining day length (Snodgrass et al. 2013). However, emergence from diapause by the adults from Springfield was significantly slower than it was for adults from Stoneville, MS. This indicated that TPB populations in areas where winter hosts occur have been selected for faster emergence from diapause.

Movement. A critical part of developing control measures for most pest species is knowledge of how far they move in time and the environmental and physiological factors which trigger the movement. TPB movement is incompletely understood. The longest documented movement of the TPB was 4.8 km while in sustained flight (MacCreary 1965). Stewart and Gaylor (1994) used a flight mill and found that the individuals with the longest flight duration were young parous females. This finding supported their observations that early-reproductive females were more likely to colonize new habitat patches (Stewart and Gaylor 1991). Several studies on flight height and time of flight have been conducted using traps. Mueller and Stern (1973) used sticky traps to monitor the flight activity of *Lygus hesperus* Knight and *L. elisus* Van Duzee. They found that most flights for both species were between one and four feet from the ground. The period of greatest flight activity was twilight. Butler (1972) used truck-mounted traps to collect *L. hesperus*. He caught the highest number one hour after sunset and near sunrise. Most flight was between 2.5 and 9.5 ft. above ground. Stewart and Gaylor (1991) found that 88% of trap collected TPB were caught within 1.8 m of the ground.

Traps. Virgin female TPB release an unidentified pheromone to attract males for mating (Scales 1968). In several studies (Scales 1968, Graham 1987, Scott and Snodgrass 2000), virgin females have been used to attract males for capture in sticky traps. Scales (1968) found that females greater than one week of age were more attractive than younger females. Traps baited with one, five, or ten virgin females captured higher numbers of male TPB as the number of females used as bait in the traps was increased (Scott and Snodgrass 2000). Efforts to develop a synthetic female pheromone to attract males to traps have been unsuccessful. Trap height can affect trap capture of *Lygus* spp. Traps placed 1-2 m above the ground captured more adults than those at higher or lower heights (Prokopy et al. 1979, Capinera 1980, McPherson et al. 1983). Trap color can also affect trap capture. Prokopy et al. (1979) caught significantly more TPB with sticky coated non-UV reflecting white or Zoecon Yellow rectangles compared to several other colors of sticky-coated rectangles. Because of the lack of a long lasting synthetic female pheromone lure, traps are rarely used to detect or suppress TPB populations in crops.

Parasites. The mymarid egg parasite of *Lygus* spp., *Anaphes ovijentatus* Crosby and Leonard, is the major parasite of *Lygus* spp. In the United States (Clancy and Pierce 1966, Sillings and Broersma 1974). This parasite is multivoltine and found throughout the eastern United States. It parasitizes eggs of *L. lineolaris* and three other species of Lygus. In the laboratory it will also parasitize eggs of the mirid *Polymerus basilis* (Reuter). *P. basilis* is an abundant mirid in the mid-South and occurs on several of the same host plants as TPB (Snodgrass et al. 1984c). Despite the abundance of TPB and *P. basilis* in the mid-South, *A. ovijentatus* is not commonly found in the mid-South (GLS unpublished data). The most frequently found parasites of TPB nymphs and adults are euphorine species in the genera *Leiophron* and *Peristenus.* Adults in these genera attack early-instar nymphs and the resulting single parasite larvae kill and emerge from the fifth instar nymph. In some cases development of the larvae is arrested until the host is an adult (Leston 1961, Loan 1965, 1966). Scales (1973) reported the first study on parasitoids of the TPB from the southeastern United States. The most abundant parasitoid he found in the Mississippi River Delta was the braconid wasp *Peristenus pallipes* (Curtis). Parasitism of TPB by *P. pallipes* reached a maximum of 62% in some weed fields in June. He also found TPB parasitized by *P. pallipes* on tall goldenrod and white heath aster, *Symphyotrichum pilosus* (Willd.) Nesom, in September. However, *P. pallipes* is univoltine and the parasites of the TPB on tall goldenrod were probably *P. pseudopallipes* (Loan) which is nearly inseparable morphologically from *P. pallipes*. Snodgrass and Fayad (1991) found parasitism rates of 8 and 32% for TPB collected in June from weeds near cotton or from weeds in undisturbed areas away from cotton, respectively. The larvae of these parasites emerged from late-instar nymphs and from adults. No adult parasites were obtained and the parasite species could not be determined. Since undisturbed areas are rare in the Delta, and the parasite was univoltine, it is doubtful that it had much of an impact on the TPB population. Multivoltine parasites which parasitize several generations of TPB would have a better chance of reducing TPB populations in the mid-South. To try and establish a multivoltine parasite, two different parasite species have been reared at the Southern Insect Management Research Unit (SIMRU), USDA-ARS, Stoneville, MS using TPB nymphs. The braconid wasp *Leiphron schusteri* Loan was imported from Kenya where its hosts were the mirids *Taylorilygus virens* (Taylor) and *T. vosseleri* (Poppins) (Snodgrass et al. 1990). It was hoped that *L. schusteri* would become established on the TPB in the mid-South and that the presence of *T. pallidulus* Blanchard, a common mirid found on many of the same plants as the TPB (Snodgrass 1984c), would aid in its establishment. However, the parasite did not become established (GLS unpublished data). In the late 1980's, *Peristenus digoneutis* Loan, was imported from Europe and released into alfalfa, *Medicago sativa* L., fields in Delaware to control TPB (Day et al. 1996). Establishment was successful and *P. digoneutis* has now spread into several new areas where it has had a significant impact on TPB populations in alfalfa. *P. digoneutis* was also reared at SIMRU and released in alfalfa for TPB control in the Delta of MS. This release was unsuccessful since it was found that the parasite could not overwinter at southern latitudes (personal communication with Bill Day). There is currently a need in the mid-South for a multivoltine parasite for TPB control.

Cultural Control. Only one non-insecticidal control method has been developed to reduce TPB numbers in cotton (Snodgrass et al. 2005, 2006). This method uses a single application of a herbicide in cotton-growing areas in March to kill broad leaf plants (TPB hosts) in marginal areas near fields, ditches, and roads. Using this treatment in large (23 Km^2) areas of the Mississippi Delta caused a significant reduction in overall mean numbers of TPB found in cotton grown in the treated areas (as compared to TPB numbers found in cotton grown in untreated areas) in June and July over a 3-yr-period (1999-2001). The average reduction in TPB numbers in cotton in the treated areas was 50%. Control of weeds in marginal areas is practiced throughout the mid-South for TPB control and because of herbicide resistance in several weed species. Because of recent changes in the proportion of land planted to the four major crops in the mid-South, the effectiveness of a single herbicide application in March needs to be reevaluated. This control method was evaluated in a time in which no maize and very few early soybeans were grown in the test areas. Currently, early soybeans and maize are extensively grown in the mid-South. Early soybeans bloom in May and can attract TPB back into a herbicide treated area in which there would be very few wild hosts. The new generation of TPB produced on soybeans could then migrate in June to cotton or maize in the treated area since both crops bloom during June and are attractive to TPB. An alternative to destroying TPB wild hosts in March would be to destroy the wild hosts on which the overwintering generation is produced in September with herbicides or mowing. An additional herbicide application in November would eliminate the two main TPB winter hosts, henbit and shepherd's purse, along with several other hosts such as clover or curly dock which emerge in the fall. These control strategies have not been extensively tested but could be conducted by producers, and could be combined with destruction of wild hosts in March. The main problem in testing these control methods is a lack of knowledge of movement by adult TPB in the fall and spring.

Mycoinsecticides. *Beauveria bassiana* (Balsamo) Vuillemin is one of the most widely researched and efficacious species of entomopathogenic fungi with pathogenicity to>200 different species of insects (Feng et al. 1994). GHA is the *B. bassiana* isolate used in Naturalis-L, a commercially available isolate (Fermone Corp.). GHA has been extensively tested in cotton for insect control and was found to produce varying amounts of TPB control (Wright and Chandler 1991, Knutson and Moore (1994), Schuster and Schuster 2004, Snodgrass and Elzen 2004, Leland and McGuire 2004). In most cases it was less effective in reducing TPB populations as compared to a standard insecticide treatment. A strain of *B. bassiana* (NI8) was isolated from an infected TPB found in Washington County, MS. NI8 was found to be more than 10 times more pathogenic to TPB than GHA (Leland and McGuire 2004, Leland and Snodgrass 2004). The NI8 isolate has been cultured at SIMRU since 2007 and conidia from the isolate can be produced in amounts needed for field testing. Field tests with NI8 alone and in combination with the insect growth regulator novaluron (Diamond) have been conducted using wild hosts and cotton. Results of these tests have not been published (GLS), but when NI8 was used with novaluron in cotton, control of TPB was as good as that obtained with standard insecticides and better than that obtained with NI8 or novaluron alone. Novaluron primarily controls nymphs, while NI8 is more effective against adults. Field tests with NI8 on TPB populations found on wild hosts in September and October have produced mixed results and additional testing is needed. The use of NI8 to control TPB on wild hosts in September and October could be an effective way of reducing overwintering TPB populations, especially if it is used prior to the use of a herbicide or mowing treatment to destroy the hosts and TPB eggs and nymphs on them. The use of NI8 alone or in combination with novaluron in maize to reduce TPB numbers before they migrate to cotton is a possible control method. This could never be used on all maize acreage, but if the distribution of TPB in maize is unequal (with higher numbers near field borders), then use of this control method in maize edges bordering cotton fields is possible. The distribution of TPB in maize is unknown.

Nectariless Cotton. One host plant resistance trait found in cotton cultivars occurs in plants with fewer or no intra- and extra-floral glands (nectaries). Nectar secreted by nectarines attracts and provides food for many pest and beneficial insects. The nectariless trait reduces TPB numbers by reducing female fecundity (Bailey 1982, Bailey et al. 1984). Meredith (1998) reported that 10 studies showed reductions in TPB numbers ranging from 26.2 to 66.6%, with an average reduction of 48.8%. Nectariless cotton can also reduce numbers of beneficial arthropods. Schuster et al. (1976) found a 34.8% reduction in total beneficial arthropods. Scott et al. (1988) found total predators were reduced 27.2%. Nectariless cotton varieties could be a useful component in an integrated control program for TPB in the mid-South, but little nectariless cotton is grown in the mid-South.

Insecticide Resistance. Research in the 1960's and 1970's found that during early season (presquaring and square production to early bloom) damage to cotton by the TPB could result in yield loss and delays in fruiting and boll maturity (Laster and Davis 1967, Scales and Furr 1968, Tugwell et al. 1976, Hanny et al. 1977). During this time, the TPB was considered to be a secondary pest that was controlled in cotton by insecticide applications made for boll weevils, *Anthonomous grandis* Boheman, or bollworms, *Helicoverpa zea* (Boddie), and tobacco budworms, *Heliothis virescens* (F.). Entomology departments in the mid-South taught the use of integrated pest management to control cotton pests and conservation of beneficial arthropods was at the center of this control strategy. Beneficial arthropods were needed to help control bollworms and budworms, which were difficult to control with the available insecticides. The use of insecticides to control only TPB was not recommended since it was well known that cotton could compensate for TPB damage and yield loss during the growing season. However, this compensation required a longer growing season and often resulted in delayed crop maturity. This made the cotton crop more vulnerable to late season damage by lepidopterous pests and poor harvest conditions often found in the fall due to bad weather. Research in 1984 (Scott et al. 1986) showed that TPB damage in early season during the first 4-5 weeks of squaring caused significant yield loss in cotton. It also caused a delay in cotton maturity. An economic analysis of the test results greatly increased the impact of the research since it found that a delay of 1 wk. in harvesting reduced yield by 7%, while a 2 wk. delay decreased yield 16% (Parvin 1985). Yield reduction was due to decreased picker efficiency over the harvest season. These results changed the status of the TPB to that of a serious early season pest of cotton and this caused several changes in cotton production. One change was that seed companies started producing shorter season varieties. Early maturing cotton varieties in 1978 accounted for an average 16.7% of mid-South states cotton. The average for early maturing varieties in 1986 was 89.5% (Bridge and McDonald 1987). Growers and consultants made use of pyrethroid insecticides (which came out in 1977) to control TPB. Since the pyrethroids controlled most cotton pests (not boll weevils), they could make automatic applications to increase yields without having to worry about the destruction of beneficial arthropods. Aldicarb (Temik) was also extensively used at rates up to 1.13 kg (AI)/ ha. Aldicarb did a good job in controlling thrips and could suppress TPB for 7- to 8-wk when used at 1.13 kg (AI)/ ha (Scott et al. 1985). Pyrethroids remained effective for TPB control until 1993. Plant bugs were found in cotton in 1993 in the delta of Mississippi that were highly resistant to pyrethroid insecticides with cross resistance and multiple resistance to some organophosphate and cyclodiene insecticides (Snodgrass 1996b). This resistance spread rapidly and was found throughout the delta of AR, LA, and MS in 1995 (Pankey et al. 1996, Hollingsworth et al. 1997). Pyrethroid resistance was found to be recessive and the resistance changed each year with the most resistant populations found in the fall (after exposure to insecticides in cotton during the growing season) compared with the spring (Snodgrass and Scott 2000). To monitor TPB populations for pyrethroid resistance, a glass-vial bioassay was developed (Snodgrass 1996a) that determined LC_{50} values (the dose at which 50% of a population is killed). Resistance ratios were calculated by dividing the LC_{50} value for a test population by the LC_{50} value for a susceptible TPB population. In addition, a discriminating-dose bioassay was developed (Snodgrass and Scott 1999) to rapidly (3 h) determine the resistance level. Field and spray-table tests were used to show that when the percent mortality in the discriminating-dose bioassay was <70%, the population would be difficult to control in cotton with pyrethroid insecticides. Pyrethroid resistance in 20-25 TPB populations from the AR, LA, and MS delta was monitored by scientists at SIMRU with the discriminating-dose bioassay each year from 2000 through 2013. This monitoring program showed that pyrethroid resistance has remained in TPB populations in the mid-South with at least 50% of the test populations having high levels of resistance each year except for populations tested in 2011 (Fig. 1). The reason(s) for the decline in resistance in 2011 is unknown.

Once pyrethroid resistance developed, the insecticide of choice for TPB control was acephate (Orthene). The original pyrethroid resistant TPB tested in the 1990's was susceptible to acephate (Snodgrass 1996b). Because of the extensive use of acephate for TPB control, scientists at SIMRU began monitoring populations (20-25 per year) for resistance to acephate in 1998. A glass-vial bioassay (Snodgrass 1996a) was used along with field tests to show that when a TPB population had a resistance ratio of 3.0 or higher, the population would not be controlled with acephate in cotton (Snodgrass et al. 2008b). Five populations with resistance ratios >3.0 were found in 1999 (Fig.2), however resistance declined and remained low from 2000-2004. Resistance increased in 2005, remained the same in 2006, and then greatly increased to 70-80% of the populations tested from 2007 through 2012. The number of resistant populations declined to their 2005 and 2006 levels in 2013. The reason(s) for the decline is not known. Laboratory tests were used to show that acephate resistance was semi-dominant and that acephate resistant populations could be cross-resistant to other organophosphates with multiple resistance to pyrethroids and carbamates (Snodgrass et al. 2008b).

Several chloro-nicotinyl insecticides have been registered for control of TPB in cotton over the past ten years. These include acetamiprid (Intruder), imidicloprid (Trimax), and thiamethoxam (Centric). These insecticides are important in dealing with the insecticide resistant TPB populations found in the mid-South because they are a different class of insecticides. No resistance to them has been reported for TPB and they can be alternated with other classes of insecticides in the field to help control insecticide resistance. Imidicloprid has little contact activity for TPB, while thiamethoxam is active by ingestion and has some contact activity. To monitor TPB populations for resistance development to imidicloprid and thiamethoxam, a glass-vial bioassay for determining LC_{50} values was developed (Snodgrass et al. 2008a). In this bioassay, adults are fed different doses of the insecticides using a honey-water solution. Results from monitoring 10-25 TPB populations in the delta of AR, LA, and MS each year since 2006 have shown that some populations have a small amount of tolerance to imidicloprid and thiamethoxam which goes up and down from year to year (GLS unpublished data). However, no consistent upward trend for resistance development was found. Scientists at SIMRU are also developing a bioassay to study resistance development in TPB to novaluron (Diamond). Novaluron is an insect growth hormone mimic which is very widely used in the mid-South to control TPB nymphs in cotton.

In summary, the TPB is very well adapted to its habitat in the mid-South. It has become the number one pest of cotton in this area because of its ability to develop resistance to the insecticides used for its control in cotton. Technical and agricultural changes in crop production in the mid-South have favored increased numbers of TPB in cotton. As long as insecticides are the main method for controlling TPB in cotton, the TPB will remain a serious pest.

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