A REVIEW OF CHEMICAL CONTROL OF THE TARNISHED PLANT BUG IN COTTON

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ABSTRACT

Research addressing insecticide control of the tarnished plant bug (TPB), *Lygus lineolaris* (Palisot de Beauvois), began during the 1930's. During this time calcium arsenate, paris green, and sulphur, which were used to control other cotton pests, also provided control of the TPB. During the 1940's, mixtures such as chlorinated camphene + sulphur, DDT + sulphur, and benzene hexachloride + sulphur suppressed the TPB. During the 1960's, other organochlorine insecticides such as dieldrin, endrin, strobane, and toxaphene were new cotton insecticides that also provided control of the TPB. Malathion was one of the first organophosphate insecticides used for cotton insect management. The carbamates, aldicarb and carbaryl, and the organophosphates, monocrotophos, and acephate, were registered for use in cotton during the 1970's and provided effective TPB suppression. The pyrethroid insecticides were first registered for use in cotton in 1978, and while not specifically recommended for TPB control, they were very effective against them. Other organophosphate insecticides, such as azinphos-methyl, chlorpyrifos, dicrotophos, dimethoate, and trichlorfon were used for TPB control during this time. Some of the organophsophate, pyrethroid, and carbamate insecticides were used for TPB control for many years without documented instances of insecticide resistance. However, pyrethroid resistance was first detected in 1993 in a field population of TPB in the Mississippi Delta. Resistant insects were also found to have multiple resistance to some organophosphate, carbamate, and cyclodiene insecticides. The level of control with organophosphate, carbamate, and pyrethroid insecticides has decreased drastically over the past several years, and new chemistry is needed to manage resistant populations in cotton. Imidacloprid (a imidazolidinimine registered for cotton use during the mid-90's) and fipronil (a phenyl-pyrazole which should be registered for use in cotton in 2000) are both new classes of insecticides that have shown excellent activity on TPB that are highly resistant to other classes of insecticides. Actara (class thiamethaozam) chemistry continues to show good activity on TPB with expected registration in 2001.

LITERATURE REVIEW

Prior to the 1940's there are few references to the tarnished plant bug (TPB), *Lygus lineolaris* (Palisot de Beauvois), as an economic pest in cotton. At the meeting of the Association of Cotton States Entomologist (Hinds 1920) held in Vicksburg, MS, no mention was made of the TPB. Parencia (1978) reported that work on the biology and control of *Lygus* was begun in the 1930's in Louisiana. Mixtures of calcium arsenate, or paris green and sulphur, gave effective control but were later replaced by the organic insecticides in the late 1930's and early 1940's after the TPB was determined to be a cotton pest. Much of the information on chemical control of TPB in cotton for the next 30 years is found in the USDA Conference Reports (1947-81). These conferences were a segment of the early Beltwide Cotton Production and Research Conferences. Those in attendance at the early cotton conferences were cotton entomologists and associated cotton specialists from state experiment stations and the Cooperative Extension Service, entomologists from USDA/ARS, industry groups, and members of the National Cotton Council. In 1947 it was reported that chlorinated camphene (10%) + sulphur (40%), DDT (5%) + sulphur (75%), and benzene hexachloride (3%) + sulphur (40%) all gave adequate suppression of the TPB. In the 1949 conference, it was reported that the TPB sometimes caused injury and had not received enough attention in the past. All in attendance at the Cotton Conference in 1953, for the first time, agreed that the TPB was often a serious pest of cotton. TPB was mentioned again as a serious pest in the 1954 conference, and all agreed that good TPB control could be obtained with any of the organic insecticides that were recommended for control of the boll weevil, *Anthonomus grandis* (Boheman), or bollworm, *Helicoverpa zea* (Boddie). During the 1957 meeting, attendees reported that the TPB was recognized as a serious pest of cotton that caused damage to squares, blooms and small bolls. Throughout most of the 1960's the tarnished plant bug continued to be a serious pest that was reduced with dust or sprays of aldrin, DDT, dieldrin, endrin, malathion, strobane and toxaphene. By 1971, other insecticides such as azinphos-methyl, carbaryl, dicrotophos, dimethoate, and trichlorfon were recommended as either a dust or spray. Aldicarb applied in-furrow was reported by those attending the Cotton Conference as being effective on TPB. During the 1972 conference, mixtures of insecticides such as carbaryl + methyl parathion, toxaphene + DDT, and toxaphene + methyl parathion, were recommended. Monocrotophos in 1974, and acephate in 1977 were added as recommended insecticides for TPB in cotton. Most insecticides applied to control cotton pests were applied as sprays.

Even though researchers had recognized for years that the TPB was a potentially serious pest of cotton, Laster (1976) reported that the damaging effects of TPB feeding on cotton remained highly controversial. Opinions among research and extension entomologists, consultants, cotton specialists and producers ranged from "key pest" to one whose damage was greatly exaggerated. This was due, in part, to the fact that most boll weevil and bollworm insecticides effectively controlled TPB. Scales and Furr (1968), Tugwell et al. (1976), and Hanny et al. (1977) further documented that the TPB could cause abnormal plant growth, fruit damage, a delay in fruiting, and delayed boll maturity.

During the Cotton Conference in 1978, insecticides recommended for TPB control were acephate, azinphos-methyl, carbaryl, chlorpyrifos, dicrotophos, dimethoate, malathion, methyl parathion, monocrotophos, toxaphene, and trichlorfon. The pyrethroids registered for bollworm/budworm, *Heliothis virescens* (F.), control in cotton in 1978 were not specifically recommended but provided excellent control of TPB. It was during this time that some insecticides (chlorpyrifos, dimethoate, and dicrotophos) were applied specifically for TPB control.

Langston and Schuster (1981) reported that Temik applied in-furrow at 0.25 and 0.50 lb AI/acre reduced TPB populations significantly below those found in the check in small plots. In the same test, foliar applications of methyl parathion (0.1), azinphos-methyl (0.125), dimethoate (0.11 and 0.23), and acephate (0.1, 0.2 and 0.4) (lb AI/acre) failed to provide adequate control. Foliar application of acephate at 0.2 lb AI/acre at pinhead square was equal in control to two applications of 0.1 lb acephate at 6-d intervals and was not disruptive to predators. Muehleisen and Gaylor (1981) reported that dimethoate (0.1), dicrofophos (0.1), trichlorfon (0.1), chlorpyrifos (0.2) and EPN + methyl parathion (0.2) (lb AI/acre), significantly reduced TPB nymphs below the check at 2 d post treatment. There were no significant differences between treatments in adult TPB populations. Lentz (1982) reported that chlorpyrifos

(0.25), malathion (0.13), dimethoate (0.1), acephate (0.2), cypermethrin (0.04), dicrotophos (0.1), and sulprofos (0.25) (lb AI/acre) significantly reduced TPB nymphal counts below those in the untreated check in a small plot test at 72 h post treatment. Muehleisen and Gaylor (1982) reported that in 1-acre plots, TPB averaged 3585 adults and 9166 nymphs per acre. Sulprofos (0.15), dimethoate (0.10), and permethrin (0.10) (lb AI/acre) significantly reduced adult TPB 2 d after treatment. The same treatments, in addition to methomyl (0.15) and dimethoate (0.10) (lb AI/acre), reduced nymphal populations 2 d post treatment, and all but dimethoate significantly reduced nymphs for up to 2 wk post treatment. Mullins and Gallaher (1982) reported that in 16-row plots (100 ft long), dimethoate (0.10), methomyl (0.125), acephate (0.10), chlorpyrifos (0.25), and sulprofos (0.25) (lb AI/acre) significantly reduced the 1 d and 3 d post-treatment counts of TPB below the untreated check. The dimethoate, chlorpyrifos, and sulprofos treatments had a significant reduction in numbers of TPB at 7 d after treatment. Gallaher and Kowalski (1983) reported that sulprofos (0.25), dimethoate (0.10), and methomyl (0.125) (lbs AI/acre) significantly reduced TPB numbers below the untreated check at 1 d after treatment. There was no significant difference in TPB numbers between the check and cypermethrin (0.02 lbs AI/acre) treatments during the same period. TPB numbers at 3 d and 7 d post treatment were significantly less than those found in the check. Micinski (1983) reported that oxamyl (0.125), flucythrinate (0.04), and dicrotophos (0.10) (lbs AI/acre) had the highest level of TPB control at 2 d post treatment. Fenvalerate (0.10) and flucythrinate (0.04) (lb AI/acre) were the most effective in the second test at 8 d post treatment. Wilson and Luttrell (1983) reported that in a small plot test in cotton that utilized thirteen different insecticides no significant differences occurred between treatments and the check for numbers of TPB. In this test, pre-treatment populations were low. Gallaher and Kowalski (1984) reported that dimethoate (0.10), cypermethrin (0.02), and methomyl (0.125) applied to cotton in water and oil, and sulprofos (0.25) (lbs AI/acre) applied in water, significantly reduced the 1 d and 3 d post treatment counts of TPB below the untreated check. Maredia and Tugwell (1984) caged TPB on cotton plants sprayed with various rates of seven different insecticides and found that all treatments had significantly lower numbers of TPB than were found in the untreated check, although the level of control was lower with chlordimeform and a low rate of cypermethrin. It was found that good control of TPB was obtained with mexacarbate (0.10, 0.20, 0.50 and 1.0), dimethoate (0.10), and cypermethrin (0.04) (lb AI/acre), when TPBs were confined to treated cotton plants with sleeve cages. Fenvalerate (0.10 lb AI/acre) provided moderate control.

Scott et al. (1985a) reported that TPB was the main early season pest in a large plot study in cotton from 1981-83. Aldicarb was applied in-furrow in 1-acre plots at 0.25, 0.50 and 1.0 lb AI/acre and compared to dimethoate at 0.20 lbs AI/acre as a foliar spray. All rates of Temik suppressed TPB, although the high rate gave the most consistent control for 7-8 wk. Scott et al. (1985b) reported that relatively high TPB populations in 1979 caused a decrease in the rate of squaring and a delay in peak squaring when compared to lower populations in 1978 and 1980. When Luttrell (1985) surveyed various cotton entomologists as to the status of TPB as a pest of cotton, he found a considerable variation in the opinions of those surveyed as to its importance. Burris et al. (1985) and Pfrimmer (1985) considered the TPB to be a minor or secondary pest.

Burris et al. (1986) found that TPB populations were reduced more with treatments of dicrotophos (0.2), and fenvalerate (0.1) (lb AI/acre) than with dicrotophos (0.1) and chlordimeform (0.125) (lb AI/acre). Graham and Gaylor (1986) reported that treatments of lambda-cyhalothrin (0.01, 0.02), malathion (0.125), dicrotophos (0.2), sulprofos (0.25) and cypermethrin (0.03) (lbs AI/acre) had significantly fewer TPB nymphs than the untreated check plots. There were no differences between fluvalinate (0.05 lb AI/acre) and the untreated check. Leonard et al. (1986) reported that TPB and cotton fleahoppers, *Pseudatomoscelis seriatus* (Reuter), were significantly reduced with dimethoate (0.20), malathion RTU (0.50), and chlorpyrifos (0.185 and 0.25) (lb AI/acre). Scott et al. (1986) tested four classes of insecticides for TPB and cotton fleahopper control (Treatments were: dimethoate (0.15), chlordimeform (0.125), flucythrinate (0.025), fenvalerate (0.10) (lbs AI/acre)) alone and in combination with aldicarb (0.50 lb AI/acre), applied in-furrow at planting. The untreated check was not treated until after the 1st week of July. Populations of the TPB at this time in the untreated check averaged 20,000 per acre. Cotton yields in the dimethoate, fenvalerate, and flucythrinate treatments had a higher percent harvested during first pick and higher total yields than that harvested in the chlordimeform treatment and untreated check. High TPB populations in this test resulted in a delay in maturity, and yields in the untreated check were over 300 pounds of lint less than lint yields harvested in the fenvalerate treatment. Luttrell and Reed (1986) stated that the development of several pyrethroids since 1978 had greatly expanded the arsenal of these insecticides. Prices of the pyrethroid insecticides during the mid 1980's declined, and this expanded the use of these compounds, causing considerable controversy over their proper use, especially in early season.

Leonard et al. (1987) reported that TPB populations in cotton were reduced significantly below the level of the untreated check with treatments of dicrotophos (0.20), cypermethrin (0.04 and 0.06), malathion RTU (0.82), lambda-cyhalothrin (0.015 and 0.02), and methamidophos (0.25) (lbs AI/acre). Reed and Hurst (1987) evaluated eleven different insecticides for TPB control. Control of the TPB nymphs in cotton was good in all treatment plots except those treated with the experimental insecticide M0070616. There were no significant differences in adult populations. Schuster and Langston (1987) tested several experimental insecticides as well as cypermethrin (0.04) and oxamyl (0.215) (lbs AI/acre) for TPB control in cotton field plots. None of the treatments provided good initial reduction in numbers of nymphs. Cypermethrin clearly provided the better TPB control, several days into the test. Aerial application studies with bifenthrin by Mitchell et al. (1987) at 0.06 and 0.08 lb AI/acre gave excellent control of TPB when applied ULV in vegetable oil.

Snodgrass and Scott (1988b) studied the toxicity of dimethoate and acephate on TPB collected in different areas of the Mississippi Delta. Results showed that TPB collected in late May or early June were as much as 4.8 times more tolerant to dimethoate when compared to those collected from non-Delta areas. Tolerance to dimethoate in TPB collected in the Delta in mid-October declined at most locations but was still 2 to 3 times higher than tollerance in the non-Delta locations. Little tolerance to acephate was found at any location for TPB collected in the spring or fall. Treatments of dicrotophos (0.20), methomyl (0.125) and lambda-cyhalothrin (0.02) (lbs AI/acre) had significantly fewer adults and nymphs than an untreated check at 2 d post treatment (Graham and Gaylor 1988). Langston and Schuster (1988) found that monocrotophos at 0.5 lbs AI/acre was effective 1 d and 7 d after application but not at 8 d, and dicrotophos was slightly improved with the addition of chlordimeform, although control with monocrotophos was unaffected. All treatments included in the test provided good control when compared to the check but showed little evidence of synergism. Snodgrass and Scott (1988a) applied several insecticides with/without chlordimeform to large field plots to determine their effects on moderate TPB populations; treatments reduced populations significantly below the untreated check. Wells et al. (1988) caged TPB on cotton in small plots after treatment to determine initial mortality and 24 h after treatment. When TPB were exposed immediately following treatment, chlorpyrifos (0.25 lbs AI/acre) and the experimental insecticide XRM-4656 (2 pt/acre) performed better than thiodicarb (0.60 lbs AI/acre) and the lower rate of XRM-4656 (1 pt/acre). All insecticides caused significant mortality as compared to the check. When TPB were exposed 24 h after application, only chlorpyrifos, XRM-4656 (2 pt/acre) and thiodicarb were better than the check. Langston and Schuster (1989) reported that populations of the TPB were not controlled effectively by different insecticides applied at various rates. Dicrotophos (0.50 lb

AI/acre) provided the best control over a 7-d period. TPB numbers increased rapidly after good knock-down with bifenthrin and cypermethrin at 0.06 lb AI/acre. Leonard et al. (1989) in a small plot test showed that thiodicarb (0.125), amitraz (0.25 lb), profenofos (0.25), sulprofos (0.25), and methamidophos (0.25) (lbs AI/acre) significantly reduced TPB numbers when compared to the check. Micinski et al. (1989) determined the effects of seven insecticides on populations of the TPB. In the study, acephate (0.25), chlorpyrifos (0.25), sylprofos (0.25), profenofos (0.25), and amitraz (0.125) (lbs AI/acre), significantly reduced the number of TPB when compared to the untreated check after three applications. Treatments with chlordimeform (0.125) and thiodicarb (0.125) (lbs AI/acre) did not differ from check.

Dacus et al. (1990) determined the level of TPB mortality on cotton plants sprayed with various insecticides. Insects were confined to treated plants with organdy sleeve cages. Sulprofos (1.0 lb AI/acre) was the most effective, fenpropathrin (0.2), tralomethrin (0.018), and oxamyl (0.125) + piperonyl butoxide (0.125) (lbs AI/acre) also provided control but primicarb and amitraz were ineffective. Langston and Schuster (1990) reported that TPB populations were not controlled by in-furrow applications of various granular insecticides. In a field evaluation of nine insecticides, Micinski et al. (1990) reported that at 48 h post treatment only profenofos (0.25), acephate (0.25), and azinphos-methyl (0.25) (lbs AI/acre) had significantly fewer TPB / 50 sweeps compared to the untreated check. Dacus et al. (1991) studied the level of TPB control in cotton sprayed with dimethoate (0.20 lbs AI/acre) and a spreader sticker, Plex. When TPB were exposed to the treated plants for 72 h,. Dimethoate provided adequate control for 24 h, but Plex did not extend the duration of control. In a field study of twelve insecticides for TPB control, Micinski et al. (1991) found that TPB populations were significantly reduced by all treatments at 4 h and 48 h post treatment compared to the check. At 5 DAT, only oxamyl (0.25 lb AI/acre) and dimethoate (0.20 lb AI/acre) significantly reduced TPB numbers compared to the untreated check. Scott and Adams (1992) evaluated in-furrow and foliar treatments in 30- and 38-in row spacings of cotton. TPB in the large field plots did not reach economic levels, although populations were lower in both row spacings in the aldicarb treatment (0.50 lbs AI/acre) than observed in treatments of acephate granules applied in-furrow (1.0 lbs AI/acre) or a foliar treatment with dimethoate (0.20 lbs AI/acre). In field efficacy trials conducted by Mitchell and Hatfield (1993) to evaluate insecticidal activity, zeta-cypermethrin controlled TPB equally to lambda-cyhalothrin (0.028), cyfluthrin (0.03), esfenvalerate (0.034), and tralomethrin (0.019) (lbs AI/acre).

In 1989, university and USDA researchers began evaluating as many as five formulations of fipronil for control of TPB in cotton. Burris et al. (1994) reported that the efficacy of fipronil for TPB at rates of 0.0125, 0.025, 0.038 and 0.05 lb AI/acre was equal to dimethoate applied at 0.20 lb AI/acre. In further testing, fipronil significantly reduced TPB damage equal to that obtained with acephate (0.25 lb AI/acre). Snodgrass (1994) determined that TPB collected from a tolerant population in cotton at Schlater, MS, during 1993 were resistant to pyrethroids. Resistance to permethrin, as determined using a glass vial bioassay (Snodgrass 1996), was 54 times higher than permethrin resistance found in adults collected from wild hosts near cotton at Stoneville, MS. Adults from the Schlater area were 35 times more resistant to bifenthrin than adults collected at Stoneville. The TPB from cotton at Schlater had multiple insecticide resistance to several organophosphate, pyrethroid, and cyclodiene insecticides. The highest levels of resistance were to pyrethroids suggesting that the resistance resulted from selection with that class of insecticides in cotton. Snodgrass and Elzen (1995) reported that four organophosphate (acephate, azinphos-methyl, dicrotophos, and methyl parathion) two carbamate (oxamyl and carbofuran) and one cyclodiene (endosulfan) insecticides were ineffective in controlling TPB in cotton. Adults collected from the field showed significant levels of resistance (compared to a susceptible laboratory strain) to dicrotophos, methyl parathion and permethrin using a glass vial bioassay.

Bannister and Lentz (1994) reported that in a small plot test in cotton there were no differences in TPB mortality (85 to 100%) when exposed to plants treated with acephate, dicrotophos, chlorpyrifos, parathion, malathion, and sulprofos. Elzen and Snodgrass (1994) in a small plot test compared the efficacy of NTN33893 (0.022 lbs AI/acre) with/without Kinetic for TPB control to that obtained with methamidophos (0.25 lbs AI/acre) and dimethoate (0.20 lbs AI/acre). At 3 DAT there were no significant differences among treatments for adults following a second treatment (at 4 DAT); NTN33893 plus Kenetic was more effective than methamidophos (0.25 lbs AI/acre). Martin et al. (1994a) reported that numbers of TPB adults and nymphs were significantly reduced with fipronil (0.056-0.076 lbs AI/acre) and endosulfan (0.401-0.562 lbs AI/acre) to levels below that observed in treatments of chlorfenapyr (0.337-0.449), azinphos-methyl (0.281), and phosmet (0.123) (lbs AI/acre). The efficacy of different pyrethroids on the TPB was determined by Martin et al. (1994b). Adults, nymphs and total TPB numbers were significantly reduced with five registered and two experimental pyrethroid insecticides. Reed et al. (1994) evaluated 8 insecticide treatments for efficacy against the TPB. In the test, all compounds except azinphos-methyl performed well. The best TPB control was obtained with dicrotophos, EXP00720A-80WG (fipronil) and oxamyl.

Bannister et al. (1995) conducted a series of tests to determine the efficacy of as many as twelve insecticides for control of the TPB. Results indicated that there were no differences in the efficacy of acephate, dicrotopohos, malathion, oxamyl and a azinphos-methyl/dimethoate tank mix (93-96% mortality). Fipronil provided an average of 91.0% initial control with 57.5% residual control in the tests. Pankey et al. (1995) conducted three separate tests and evaluated the control of the TPB with several insecticides that included organophophate, pyrethroid, carbamate, cyclodiene, and the new phenylpyrazole chemistry (fipronil). All treatments in the test except deltamethrin significantly reduced the number of adults and nymphs below the untreated check. Reed and Jackson (1995) reported that the pyrethroids fenpropathrin, lambda-cyhalothrin, and deltamethrin provided a higher level of TPB control than dicrotophos, although mortality with all insecticides was significantly better than that observed in the water check.

Snodgrass and Scott (1996) used a discriminating dose glass vial bioassay with permethrin to determine the degree of pyrethroid insecticide resistance in populations of the TPB in the Mississippi Delta of Arkansas, Mississippi, and Louisiana. Adult TPB collected from 71 sites in the spring and 72 locations in the fall were tested for pyrethroid resistance; results showed widespread resistance and that pyrethroids should not be used to control TPB in May and June. Teague and Tugwell (1996a) conducted laboratory bioassays to evaluate responses of TPB to insecticides administered to adults in a sucrose/dye mixture. Efficacy of imidacloprid at low rates (0.02 and 0.025 lb AI/acre) was improved with the addition of sucrose or molasses. Shaw and Yang (1996) found that fipronil was highly effective for control of TPB at rates as low as 0.038 lb AI/acre. In small plot tests in cotton, they found that the 0.038 lb AI/acre rate was slightly less effective than the 0.05 lb AI/acre rate. Pankey et al. (1996c) concluded from a field test that adult TPB mortality was significantly higher with acephate (0.50) and oxamyl (0.25), when compared to cypermethrin (0.04) (lbs AI/acre) when test insects were caged 2 h after treatment.

Scott and Snodgrass (1996) utilized spray chamber bioassays and field plots to determine that fipronil 80 WG and 2.5 EC were the best formulations for TPB, producing mortalities at rates of 0.025 and 0.038 lbs AI/acre that were not significantly different from TPB mortality found in the oxamyl (0.25 lbs AI/acre) treatment. In a pyrethroid-resistant field population, more than one application of each insecticide tested was needed to control a high population in August. The effectiveness of fipronil and imidacloprid 0.047 lbs AI/acre (which are both new classes of insecticides) against high TPB populations in large cotton indicated that both insecticides could be useful in reducing insecticide resistance. Elzen (1996a) determined that imidacloprid (0.047), dimethoate (0.25), and methyl parathion (0.25) (lbs AI/acre) applied for TPB in field plots had significantly lower numbers of TPB than the untreated check. Elzen (1996b) evaluated six insecticide treatments for TPB control using sweep net, visual and drop cloth samples; few significant differences were found due to a low TPB population. Fife et al. (1996) reported that the number of TPB found in cotton plots treated with malathion (0.25,0.375), EXP-TD 2351(0.25,0.375,0.50), and methyl parathion (0.33) (lbs AI/acre) did not differ among treatments or the check. Pankey et al. (1996a) reported that at 2 DAT, only fipronil (0.025 and 0.038 lb AI/acre) produced significantly higher mortality of TPB compared to the untreated check in field plots. At 5 DAT, there were no significant differences in mortality among the fipronil treatments and treatments with acephate (0.20 lbs AI/acre) and dicrotophos (0.20 lbs AI/acre). Pankey et al. (1996b) determined that mortality of TPB caged on cotton plants and treated with several insecticides resulted in significantly higher mortality levels with all treatments except pyrmetrozine when compared to the untreated check. Reed and Jackson (1996a) tested several classes of insecticides for TPB control in cotton and found that all treatments significantly reduced numbers below the untreated check, but only carbofuran provided more than 90% control. Reed and Jackson (1996b) showed that 2 DAT, Fyfanon formulations were equally as effective against TPB as Cythion, and by 3 DAT slightly more efficacious. At 2 DAT, all treatments reduced TPB numbers significantly below that of check. Teague and Tugwell (1996b) showed that the addition of molasses to the low rate of imidacloprid (0.022 lbs AI/acre) increased mortality at 3 DAT. No effect was noticed when molasses was added to high rate of imidacloprid (0.047 lbs AI/acre). Highest mortality was observed with acephate (0.50 lbs AI/acre). Scott and Snodgrass (1996) studied the efficacy of fipronil, imidacloprid and oxamyl against a heavy population of TPB during late season in cotton and found that total numbers of TPB were significantly reduced by all treatments below the untreated control. Although not significantly different, average numbers of TPB were lower in the fipronil (0.05) and imidacloprid (0.04) treatments than in the oxamyl (0.25) (lbs AI/acre) standard. Tugwell et al. (1996) reported the highest rate of the mixture of chlorpyrifos (1.0) + methyl-parathion (0.25) provided TPB mortality equal to treatments of chlorpyrifos (0.50,1.0) and acephate (0.50) (lbs AI/acre) in two trials.

Shaw et al. (1997) summarized trials conducted with foliar insecticide sprays since 1989 and concluded that fipronil applied at rates of 0.038 and 0.05 lb AI/acre provided control of the TPB equal to or better than commercial standards. Brown et al. (1997a) evaluated Mycotrol WP504 (fungi) and imidacloprid alone and in combination; results indicated that the level of control obtained with the mixture of each at one-half the rate was equal to that obtained with the high rate of imidicloprid (0.047 lbs AI/acre) alone. In further testing of Mycotrol and imidiacloprod, Brown et al. (1997b) reported that all treatments and treatment combinations increased TPB mortality over the control for at least 24 h post application. Only those treatments with imidiacloprod killed TPB after 48 h.

Pyrethroid insecticides were still being evaluated for TPB control as late as 1997. Reed et al. (1997) reported that mortality readings taken 24 h after treatment showed that lambda-cyhalothrin (0.028) was more effective than all treatments except acephate (0.50), dicrotophos (0.40), deltamethrin (0.023), and zeta-cypermethrin (0.037) (lbs AI/acre). Seventy-two hours after treatment, cyfluthrin (0.033 lbs AI/acre) gave significantly higher TPB mortality than other treatments. Studebaker (1997a) evaluated eleven various insecticides representing six different classes of chemistry for control of the TPB and found no significant differences in the number of adults among treatments. All treatments except dicrotopohos and endosulfan provided control of nymphs. In further testing Studebaker (1997b) showed that all treatments of twelve different insecticides significantly reduced the numbers of TPB at 3 DAT. The efficacy of acephate and profenofos on TPB was determined in sleeve cage studies by Teague and Tugwell (1997a). Highest mortality recorded in the test (90%) was with the acephate (0.50 lbs AI/acre) treatment as compared to 60 and 68% with the high and low rates of profenofos (0.50,0.25 lbs AI/acre, respectively). Teague and Tugwell (1997c) reported the results of a test to determine mortality of the TPB exposed to chlorpyrifos (0.0625,0.12,0.25,0.50,1.0) + methyl parathion (0.25), chlorpyrifos alone (1.0) and acephate (0.50) (lbs AI/acre). The greatest mortality was observed in the 3 higher rates of chlorpyrifos + methyl parathion and the chlorpyrifos and acephate treatments. Teague and Tugwell (1997b) reported that the highest mortality of TPB was found in treated cotton plots that received fipronil. There were no differences in mortality between two formulations of lambda-cyhalothrin. Hollingsworth (1997) collected tarnished plant bugs from 4 locations in Arkansas and tested them for susceptibility to insecticides using a glass vial bioassay. Two locations had TPB populations with higher tolerance to endosulfan than a susceptible reference (tolerance ratios of 33 and 36). One population had a higher tolerance to oxamyl (tolerance ratio of 3.6) than the susceptible population. Nymphs were significantly more tolerant (2.4-3.8x) than adults to all insecticides.

Howell and Reed (1998) evaluated four recommended insecticides and two formulations of fipronil for TPB efficacy. Small plots were sprayed and allowed to dry and sleeve cages were used to confine TPB to the treated cotton. With the exception of imidacloprid (0.047 lb AI/acre) and EXP 61096A (0.05 lb AI/acre), all treatments resulted in significantly higher TPB mortality than the untreated check. Russell et al. (1998a) compared the efficacy of cyfluthrin (0.033), deltamethrin (0.025), deltamethrin (0.025) + ammitraz (0.125 and 0.25), acephate (0.33), and imidacloprid (0.047) (lbs AI/acre) by caging TPB on treated plants. All treatments except cyfluthrin resulted in higher mortality of the TPB from that observed in the untreated check. In further testing of other insecticides, Russell et al. (1998b) found that mortality of the TPB caged on plants treated with dicrotophos, (0.2), fipronil (0.038), and acephate (0.33) (lbs AI/acre) was significantly higher compared to mortality in the untreated check. Teague and Tugwell (1998a) in small plot tests determined that numbers of TPB 4 DAT were significantly reduced in all sprayed plots as compared to the untreated check. Control with the CS formulation of lambda-cyhalothrin was less than the EC formulations. In tests of control of late season populations of the TPB, Teague and Tugwell (1998b) showed that acephate (0.50 lbs AI/acre) significantly lowered the numbers of TPB when compared to other treatments. Reductions of TPB numbers were noted with profenofos (0.50 lbs AI/acre) and EXP MP062 (0.065 and 0.11 lbs AI/acre) when compared to the untreated check, but control was not acceptable. Holloway et al. (1998) collected adult TPB from a cotton growing region in Louisiana and tested them for susceptibility to cypermethrin, acephate, and oxamyl. For all three insecticides, susceptibility decreased throughout the growing season. They also found that S,S,S,-tributylphosphate or triphenylphosate synergist decreased TPB susceptibility to cypermethrin. Treatment with piperonyl butoxide or trichloroporopynyl increased the susceptibility of TPB to cypermethrin. Luttrell et al. (1998) emphasized that the development of insecticide resistance in the TPB was a major concern for cotton growers.

Kharboutli et al. (1998) conducted several insecticide trials and showed that fipronil and imidacloprid were consistently effective on TPB. Dicrotophos and acephate were unpredictable, but tank mixes of imidacloprid + cyfluthrin, and dicrotophos + oxamyl gave good TPB suppression. Robbins et al. (1998) reported that effective TPB control was obtained with several foliar insecticides. Acephate gave the greatest reduction in nymphs and adults at 0.50 lb AI/acre, whereas several pyrethroids, including cyfluthrin, lambda-cyhalothrin, and zeta-cypermethrin gave good TPB control, but in some cases control was variable, possibly due to pyrethroid resistance. Dicrotophos (0.25 lb AI/acre), imidiachlorprid (0.047 AI/acre) and methamidophos

(0.31 lb AI/acre) provided effective control. Fipronil significantly reduced TPB population at 0.038 lb AI/acre. Teague et al. (1998) summarized TPB trials in Arkansas. In the first test, fipronil provided higher mortality than two formulations of lambda-cyhalothrin; acephate provided greater mortality than profenophos in the second, and in the third, the best TPB control was obtained with acephate (0.50) and bifenthrin (0.06) (lbs AI/acre). Snodgrass and Scott (1999) exposed a pyrethroid resistant laboratory strain of TPB to seven different insecticides and found at 24 h post treatment, TPB mortality with the high rate of fipronil (0.05) and methamidophos (0.33) (lbs AI/acre) were 97 and 100%, respectively. At 48 h post treatment, TPB mortality in the acephate (0.33) and the low rate of fipronil (0.038) (lbs AI/acre) was 77 to 80%. Mortalities at 72 h with fipronil (both rates), acephate, and methamidophos were 100%. Scott and Snodgrass (1999b) conducted laboratory bioassays to evaluate formulated insecticides for their toxicity to a susceptible laboratory strain of TPB and showed that mortalities at 24 h post treatment with methamidophos (0.33), acephate (0.33), oxamyl (0.25), and fipronil (0.038 and 0.05) was 100, 94, 97, and 100% respectively. Mortalities at 48 h with EXP 6168513 (fipronil) and EXP 61486A (fipronil) were 75 to 78% and 84% with carbaryl. Scott and Snodgrass (1999a) collected TPB from wild hosts as late instar nymphs and held them in laboratory on green beans until they were 3-4 day old adults. Mortalities at 24 h post treatment with (Exp CGA 295944) at 0.223 and 0.334 lb AI/acre were 45 to 55%. Mixture of Exp CGA 295944 and profenofos at 0.25 and 0.089 lb AI/acre, respectively, resulted in 96% mortality. Mortality with imidacloprid (0.047 lb AI/acre) was 64%, whereas profenofos, fipronil and acephate at 0.50, 0.038, and 0.33 lb AI/acre, respectively resulted in mortalities of 95 to 100%. At 48 h, mortalities in all treatments ranged from 94 to 100%. Scott et al. (1999) reported that TPB control in small plots with fipronil at 0.038-0.05 lb AI/acre and Actara at 0.046-0.09 lb AI/acre was equal to or better than TPB control with lambda-cyhalothrin, methamidophos, oxamyl and cyfluthrin at 0.028, 0.30, 0.25 and 0.03 lb AI/acre, respectively. In large plot experimental use permit trials, populations of the TPB were significantly lower in treatments with oxamyl, cyfluthrin and fipronil than in the untreated check. Harvested lint yield was higher in treatments with fipronil. Reed et al. (1999) reviewed insecticide trials in cotton for control of the TPB during the last 12 years. TPB control in cotton with pyrethroids in 1982 was 94%, as compared to 73% in 1986 and an average of 56% over the last 5 years. Average TPB mortality in 92 samples was 80% for organophosphate insecticides in 1982, while the average TPB mortality for trials conducted from 1982 to 1997 was 57%. The pest status of the TPB is very likely to increase, assuming that boll weevil eradication is successful, and that transgenic BT cotton continues to be effective on bollworm/budworm populations. Methods of control of the TPB other than insecticides are still in the future, but they are needed to decrease the dependency on insecticides.

CONCLUSION

The tarnished plant bug for many years was considered a minor pest of cotton. Control was obtained with organochlorine, organophosphate, and carbamate insecticides usually applied for other cotton pests. Although the efficacy of various insecticides within these classes for TPB has always varied, resistance high enough to cause control failure in the field with a recommended insecticide was never documented. Pyrethroids were registered for use in cotton in 1978 and the target pests were the bollworm and budworm. For several years they were highly effective also on the TPB. Resistance in TPB to the pyrethroid chemistry high enough to cause a control failure in the field was documented in 1993 after fifteen years of wide spread use. Pyrethroid resistant TPB have multiple resistance to some of the organophosphate, carbamate and cyclodiene insecticides. Since the discovery of resistance, acephate and methamidophos (organophosphates), in cotton and imidacloprid (imidazolidinimine class), have been frequently used to control pyrethroid resistant populations in cotton before and after first bloom. Pyrethroid use in cotton prior to first bloom is not recommended to avoid selection for resistance in TPB, and tobacco budworms. The control of TPB populations in cotton is presently totally dependent on effective insecticides, and will remain so for the foreseeable future, until alternative control measures are developed. The registration of fipronil and actara will greatly assist in the resistant management of the TPB by providing two new classes of effective insecticides.

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