Search for Effective Chemical Controls for Lygus Bugs and Whiteflies in Arizona Cotton

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Abstract

Whiteflies and Lygus *bugs continue to be key pests of Arizona cotton. Some of our most popular and time-tested chemicals are still providing efficacy toward* Lygus *or whiteflies when used in a timely manner. However, promising new chemicals may also become available in the near future. Through research, growers can be kept updated on options for successful IPM. An experiment was conducted in order to expand our knowledge of currently available compounds and upcoming advances in insecticide development. In this experiment, 11 different compounds were tested for efficacy and duration of activity against whiteflies,* Lygus, *or both. Although none were active on* Lygus *adults, some chemicals were very effective on all stages of nymphs. Orthene® or Vydate® continue to show good results against* Lygus *but did not yield as high as one new compound. The best performing insecticide against* Lygus *was flonicamid, a novel chemistry under development by FMC. This insecticide had the best control over* Lygus *nymphs, was the highest yielding treatment, and required one less spray than other top performing compounds. Among newer chemistries for* Lygus *control is fipronil (Regent® by BASF), which performed slightly better than Vydate but not quite as effective as Orthene. Another higher-yielding regime included the use of novaluron, a novel insect growth regulator (IGR) scheduled for registration in 2005 (Diamond® by Crompton Corporation). This IGR was tested against whiteflies and* Lygus *bugs, but in light of yield data,* Lygus *efficacy should be examined more closely. None of the neonicotinoids were effective against* Lygus, *but several proved to be promising for whitefly control. Of the neonicotinoids tested and sprayed on threshold, dinotefuran (under development by Valent) showed good activity. The performance of spiromesifin (Oberon®, a new chemistry by Bayer) was similar to dinotefuran but needing one less spray. Intruder® out-performed all whitefly treatments, requiring only two sprays to control whiteflies season-long. Both Intruder or currently used IGRs (Knack® and Courier®) proved to be very effective against whiteflies. All insecticides in this test underwent very rigorous testing under extreme* Lygus *and whitefly pressures.*

Introduction

Goal: *To enhance the ability of growers to better manage insect pests through the development of problem-solving research and outreach in cotton insect pest management.*

Arizona currently has three problematic insect pests that have the capability of causing economic damage to cotton: whitefly (*Bemisia tabaci*), *Lygus hesperus,* and pink bollworm (*Pectinophora gossypiella*). *Lygus* bugs have only become a more noticeable problem since the mid-1990s, when the introduction of Bt cotton and IGRs brought about a great reduction in the number of insecticides applied to cotton (Ellsworth & Jones 2001). Previously, *Lygus* bugs were controlled collaterally by insecticides that were applied against pink bollworm, whiteflies and even earlier in

Arizona's history, boll weevil, cotton bollworm and cotton leafperforator (Ellsworth et al. 1998b). At that time whitefly control was accomplished with harsh, broad-spectrum insecticides like pyrethroids, organophosphates, or combinations of both (Watson et al. 1994; Dennehy et al. 1995). In 1995, growers applied an average of 12.5 sprays for the control of all insect pests (Ellsworth & Jones 2001; Williams et al. 2004). In contrast, last year growers of Bt cotton sprayed an average of 3.8 times with insecticides. Breaking this down further, *Lygus* required just under 2 sprays and whiteflies required 1.3 sprays (Ellsworth & Jones 2004).

There have been dramatic changes in the frequency and way chemicals are deployed and, as importantly, there have been great advances in insecticide discovery and development during the last 10 years. The trend is toward more selective, narrow spectrum insecticides. In Arizona, growers have many options for chemical control of whiteflies. With these options in mind, growers have the challenge of selecting effective compounds that fit in with an integrated pest management program. This includes the challenge of making cost effective decisions. On the other hand, not many options are available for *Lygus* control. Currently only Orthene® or Vydate® are recommended, effective *Lygus* compounds. These broad-spectrum chemicals have been proven over years to be very active on *Lygus*. Current recommendations include the limitations of only two sprays of either, due to potentially negative impact on natural enemies (Ellsworth 1998, 1999, 2000). It is apparent that there are not enough choices for *Lygus* control, and certainly there is a need for more selective or narrow-spectrum insecticides effective against this pest.

In this experiment we tested novel unregistered chemistries along with materials currently in use. The objective in this test was to discover duration and efficacy of new chemistries in comparison to currently available compounds. As a result of tests like these, we provide growers with useful insight into alternatives for cotton insect pest management.

Methods

In 2003, a test was conducted at the University of Arizona Maricopa Agricultural Center (Maricopa, AZ) to test the efficacy of several chemicals against whiteflies and/or *Lygus*. The experiment was planted with DP458B/R (containing both Bollgard® and Roundup Ready® technologies) on 6 June. The late planting date was selected intentionally to exacerbate pest problems in the test. This experiment contained 80 plots measuring 12 rows by 33 ft. Plots from treatments T16, T17, T18 and T19 together created one large IGR block that was arranged in a randomized complete block design with all other treatments (Table 1). This test was replicated four times for a total of 20 treatments. T1–13 were tested for whitefly efficacy, T10–19 were tested for *Lygus* efficacy, and T10–13 were tested against both whitefly and *Lygus* but were only sprayed as needed for whitefly control.

There were several standards and checks within this combined field experiment. T16 served as a standard whitefly control program initiated with IGRs. T13 served as an additional, but non-IGR, whitefly standard. These same two treatments (T13 & T16) also serve as untreated controls for the *Lygus* efficacy comparisons. T0 was never sprayed for any insects and served as the untreated control for the whitefly efficacy comparisons.

All insecticide applications were made using a John Deere 6500 sprayer adapted to deliver liquid propelled by compressed air at 35 psi. Up to eight individual lines were used to apply various chemicals at 20 GPA to individual treatments, reducing travel through plots. Spray dates were up to two days after sampling. This time was needed to examine samples in the laboratory, assess the appropriate thresholds, and prepare for the next insecticide sprays.

All plots were defoliated with Ginstar® (0.125 lbs ai/A) on 21 October and on 10 November with Gramoxone Max® (1 pint / A). A two-row cotton picker was used to harvest the central four rows from each plot on 20 November. Once each harvest sample was weighed per plot, grocery bag size (grab) subsamples were taken. Grab samples were ginned on 11 December using a 25-saw gin to obtain seed and lint turnouts. Actual plot turnouts were used to calculate lint yields for all treatments.

Whiteflies

Whiteflies were sampled at least weekly using a standard leaf turn method for adults (Ellsworth et al. 1995; Naranjo & Flint 1995). For each plot, all leaves (N = 10) sampled for adults were collected, stored in plastic bags, and kept in a cooler. Samples were then closely inspected under a microscope for an accurate count of eggs and nymphs, which were categorized as small (instars 1 & 2) or large (instars 3 & 4). Counts were made on a 3.88 cm^2 leaf disk (Naranjo & Flint 1994; Ellsworth et al. 1996). All stages of whitefly were used for data analyses, but only adults were used as a determining factor for spray decisions using a threshold of 5 adults per leaf (Ellsworth et al. 1995). Some entries were not sprayed when they reached threshold as a condition of testing with industry cooperators. Testing conditions dictated that T8 and T9 only receive one application.

Lygus

Lygus were sampled at least weekly using a standard 15-inch diameter sweep net. Each plot was swept 25 times for a total of 100 sweeps per treatment. Each sweep net sample was placed into an 8x10 inch self-sealing plastic bag and frozen until all insects were lifeless. For accuracy, individual samples were then examined under a dissecting microscope to distinguish and count small (instars 1–3) or large (instars 4 & 5) nymphs and adults. *Lygus* efficacy treatments triggered for a spray when there were at least a combined nymph and adult count of 15 and at least 4 nymphs (15/4) per hundred sweeps (Ellsworth 2000; Ellsworth & Barkley 2001). As a condition of testing, T17 was sprayed only once against *Lygus*. An IGR program of Knack® followed by Courier® and then Intruder® was shared by T16, T17, T18 and T19 as a maintenance spray program against whiteflies (Table 1). Whitefly maintenance was initialized when the whitefly threshold triggered on 5 August. *Lygus* sprays were triggered on the *Lygus* threshold the subsequent week.

Efficacy and performance of chemicals was determined by analyses of insect counts and, in the case of *Lygus*, of yields. ANOVA, Dunnett's test relative to the control, and Tukey-Kramer's HSD to compare all treatments were performed using JMP 4.0 (SAS, 2000). Dependent variables were transformed as needed; raw means are presented.

Results

On 5 August, whitefly populations surpassed threshold considerably from 1 adult per leaf on 29 July to 10 adults per leaf. Whitefly control was initiated at this point for all treatments. *Lygus* treatments hit threshold on 13 August. The 'Whitefly Program' applied to T16–T19 was effective in keeping whitefly populations below economic threshold. Intruder (T14 and T15) also was very active in maintaining low whitefly populations throughout the test. This test was intentionally planted adjacent to a block of alfalfa (80 A). Historically this field has had a tendency to build high populations of *Lygus* mid-summer that then move into surrounding cotton when conditions force them out (cutting and/or drying down). This alfalfa field provided an unusually high amount of *Lygus* adults to seed our cotton test.

Whiteflies

Three rates of dinotefuran (T10–12) showed no significant differences among rates after three sprays (Fig. 1–4). This compound lasted 29 days before triggering its second spray on 5 September. The third spray occurred on 12 September (8 DAT). The dinotefuran treatments were not significantly different than the three rates of Oberon® (T3–5), which was sprayed one less time. Of the three Oberon rates, the higher rate (0.125 lbs ai/A; T4) had somewhat greater efficacy, though duration of efficacy was close for all three rates (Fig. 1–5). The first re-treatment was required on 5 September (31 DAT). Oberon compared closely to Intruder (T13) in efficacy toward whiteflies (Fig. 1–4). Both required only two sprays throughout the season, but Intruder lasted six days longer. Intruder did not reach threshold again until 10 September (36 DAT). This compound was more effective than all other neonicotinoids (Table 1).

Two treatments, currently under secrecy (T8 and T9), were limited to just one spray after which all stages of whiteflies gradually increased over time. Whiteflies did not reach threshold again until 10 September (36 DAT) (Fig. 6). Beyond 9 September, eggs, nymphs, and adults quickly increased in numbers. Overall, T8 and T9 did well compared to other treatments (Fig. 1–4), considering they were only sprayed once.

Throughout the season and regardless of repeated sprays, egg, nymph and adult populations remained high for both Diamond® rates (T1 and T2). Both treatments were not significantly different than the untreated check (T0) after five sprays (Fig. 1–4). This IGR was not effective on whiteflies despite the number of sprays it received.

The neonicotinoid Calypso® (T6) was not as active as some of the other compounds and was not significantly different from T8 and T9 seasonally (Fig. 1–4). The initial spray performed well on all stages of whiteflies and did not require a second spray until 5 September (31 DAT) (Fig. 5). However, the following spray on 12 September was not as effective. Whitefly nymphs were near the same levels as before spraying, and whitefly adult numbers tripled (Fig. 5 vs. Fig. 6). Although performance of Calypso in comparison to our whitefly standards (T13 or T16) was not wholly positive, Calypso did significantly out-perform the untreated check (T0) and Diamond (T1–2) while under extreme pressure. Earlier season comparisons of Calypso to Leverage® (T7), a neonicotinoid (imidacloprid) in combination with a pyrethroid (cyfluthrin), showed no significant differences until two sprays had been applied. Whitefly populations in the broad-spectrum Leverage treatment were significantly higher than in the more selective Calypso treatment after this point. After an initial Leverage spray, whitefly populations remained low and did not reach threshold until 26 August (23 DAT). On 3 September (7 DAT2) whiteflies triggered again at 8 adults per leaf (Fig. 5). An extremely high level of 52 adults per leaf was reached on 10 September, just eight days after the third spray of Leverage (Fig. 6). This pattern continued again reaching 42 adults per leaf on 18 September.

Lygus

Lygus adults were not controlled by the compounds tested (Fig. 10). There were no significant differences among different treatments, although seasonal average levels of adults for dinotefuran (T10) were significantly lower than the untreated check. Adult results are, however, not consistent with dinotefuran data for small (Fig. 7) and large (Fig. 8) nymph populations, which were not controlled by this compound. On the contrary, throughout the season these three treatments maintained significantly higher populations for all stages of nymphs compared to other treatments (e.g., Fig. 9). Furthermore, yield data indicated that dinotefuran was not effective in controlling *Lygus*. Yield data clearly revealed the treatments that were effective against *Lygus*: Orthene or Vydate (each combined with Intruder, T14–15), flonicamid (T18), and Regent® (T19) (Fig. 11). Diamond (T1) yield data demonstrated some *Lygus* activity when sprayed five times.

A single spray at a high rate of Diamond (T17) did not reach threshold again until 26 August (13 DAT) and showed excellent nymphal activity up to this point (e.g., Fig. 12). Yield data for Diamond (T17) was not significantly different from the check (T16) (Fig. 11), suggesting that the early *Lygus* control observed for Diamond (T17) was overwhelmed by later *Lygus* pressure in this experiment. Both flonicamid (T18) and Regent (T19) yielded significantly higher than the check (T16). After five sprays, Regent offered good nymph control and was not significantly different from the Orthene or Vydate combination with Intruder (T14 and T15, Fig. 9). Flonicamid (T18), however, was the highest yielding of all treatments and also maintained the lowest number of *Lygus* nymphs all season with the fewest sprays. Flonicamid yields were significantly higher than Orthene, Vydate, or Regent, each requiring one more spray (Fig. 11).

Two combinations of *Lygus* and whitefly insecticides were compared in T14 and T15. These combinations were initiated when *Lygus* populations reached threshold on 13 August. Both T14 and T15 provided significant control over *Lygus* (Fig. 7–10) with no significant difference between the two. Both treatments reached thresholds 7 to 8 DAT each time, requiring a total of five sprays.

Gin turnouts showed similar trends as yield data, except T7 had unusually high turnouts compared to yield and considering *Lygus* were not controlled in this treatment. Significantly higher gin (i.e., lint) and seed turnouts were obtained in both T18 and T19. Seed turnouts were significantly higher for T14 and T15. Only one treatment (T11) showed significantly lower seed turnout suggesting extensive damage by *Lygus*.

Discussion

Findings of this experiment concur with previous tests on *Lygus* chemistries (Ellsworth et al. 1998a,b, 1999; Ellsworth 1998, 1999, 2000). Currently available compounds are not directly effective on *Lygus* adults. Adult seasonal data suggests that dinotefuran might have had some effect on adult *Lygus,* despite the fact that all stages of *Lygus* nymphs were extremely high for every date sampled. In theory, a compound with IGR-like or anti-feedant properties might prevent nymphs from developing into adults. However, dinotefuran is a neonicotinoid and considering the associated low yields and high levels of nymphs for these treatments, it is more likely there was extreme square-feeding by nymphs, reducing or eliminating flowering. Reduced flowering was, in fact, observed in these plots, and when this happens, adults are forced to leave in search for or attracted to areas releasing floral attractants. Floral volatiles are well-known attractants that impact localized *Lygus* adult movement. As flower populations decline in the untreated check due to excessive square shed, *Lygus* numbers typically begin to decline. In any case, yield data clearly show dinotefuran was not effective in preventing *Lygus* damage.

Yield data is in fact the best measure for *Lygus* control. Where higher yields were realized, there were lower populations of *Lygus* nymphs. One entry in the whitefly test also showed some *Lygus* control. Diamond was tested for whitefly efficacy and sprayed repeatedly against this pest, yet it was one of the higher yielding treatments. Another entry consisted of a single spray at a higher dose of Diamond made against *Lygus*, but the restriction to one spray prevented detection of any yield benefits. The higher rate of this third generation molting inhibitor did control *Lygus* nymphs for 7–14 days, as well or better than standard and competing compounds. These findings indicate that this compound should be further tested for *Lygus* efficacy in future experiments. As an IGR, this may provide growers of cotton with a very selective tactic for control of *Lygus* as part of a larger selective strategy (e.g., including Bt cotton and whitefly IGRs) to control the entire pest complex without harming natural enemies. This selectivity may be governed in part by dosage, and future studies should carefully examine the suite of sucking Hemipteran predators that might be affected by this chemistry.

Orthene or Vydate continue to be top candidates for *Lygus* control. While both of these compounds compare closely to each other, Orthene was slightly more effective in controlling nymphs, and yields were slightly better. Both compounds were high yielding compared to nearly all other compounds. The highest yielding compound was flonicamid, a new class of chemistry with some potential selectivity. This treatment shows excellent results in efficacy toward nymphs and suppressed *Lygus* with only four sprays season-long, one less than for Orthene or Vydate. This new chemistry has previously shown strong activity against aphids, but little or no activity on whiteflies (Hancock 2004; Long et al. 2004). Among high-yielding entries was fipronil, currently registered in Australia and Mexico as a standard for mirid (plant bug) control. It is registered for corn in Arizona and around the U.S. as a soil insecticide. This chemical performed well in this and past tests (e.g., Ellsworth et al. 1999), but no efforts are being made to register fipronil as a foliar insecticide in Arizona at this time.

This experiment was planted late in the season in order for squaring to coincide with higher *Lygus* populations and to take full advantage of high whitefly populations that appear later in the season. Therefore, all data and findings were gathered under extreme pressure from *Lygus* and whiteflies. The high populations of insects reached were helpful in building a strong test for efficacy among various compounds. Under more normal conditions the compounds tested should demonstrate the same results relative to each other but actual numbers of sprays should be lower. For example, whiteflies were sprayed two or three times and *Lygus* four or five times in this test, yet historically growers have averaged ca. 1.2 sprays for whiteflies, and 1.6 times for *Lygus* (Ellsworth & Jones 2004; Williams et al. 2004).

An obstacle in this test was small plot size effects on IGRs. It has been shown previously that small plot testing for IGRs is not as representative of commercial-scale fields where spray needs are reduced. The number of sprays required decreases in large areas for IGRs due to changes in pest/beneficial dynamics (Ellsworth & Jones 2001; Ellsworth & Martinez-Carrillo 2001). In this year's test, we attempted to create larger super-plots by grouping four treatments, which used the 'Whitefly Program' to increase the area under the influence of the IGRs. However still, the area was small (80 x 80 ft) and the program did not perform as well as in commercial-scale settings.

In 2003, we also ran a commercial-scale demonstration of whitefly control technologies on blocks that were four acres in size (Ellsworth & Barkley, unpubl.). Under these conditions, Knack, Courier, or Intruder each only required one spray for season long control. Diamond is another putative whitefly IGR; however, this treatment did not show activity in our small plot trials nor in our commercial-scale demonstration where it was sprayed three times. This new IGR disrupts molting in whiteflies and is similar in function to Courier. Both compounds are contact insecticides. However, while Courier has a very active vapor phase capable of dosing leaf undersides with its fuming action, Diamond relies completely on direct contact with the nymphs by spray droplets. With cotton's large canopy and lower spray volumes, Diamond may not be reaching the target insect. Although Diamond was originally developed for control of whiteflies, it has the possibility of affecting molting processes in other insects. The specimen label indicates this compound is active on Lepidoptera and Hemiptera (true bugs). Diamond should be registered in Arizona in 2005.

The first registration for a neonicotinoid was Admire® (imidacloprid) in 1993. Currently we have four neonicotinoids registered for foliar use in cotton: Provado®, Intruder, Centric® and Leverage. In 2005, two more compounds are expected, Calypso and dinotefuran. Calypso shows good potential for whitefly control especially when compared to Leverage. The treatment containing Leverage shows a high resurgence of whiteflies after two applications, possibly by disrupting natural predators. This compound is not recommended for whitefly or *Lygus* control in Arizona. Calypso or dinotefuran each required one less spray than Leverage. Intruder continues to be one of the best options for whitefly control, only requiring two sprays during the season. Intruder was registered in Arizona in 2002, but was not registered in California until 2003 as Assail®. With the exception of Leverage (a pyrethroid mixture), the neonicotinoids have the added benefit of being narrower spectrum chemistries. None of the compounds tested had any effects on *Lygus*.

Also scheduled for registration in 2004 is a new chemistry with a novel mode of action. Oberon inhibits lipid biosynthesis and leads to dehydration of the insect (Buckelew 2002). Results from this experiment are very promising, requiring only two sprays to control whiteflies. This compound is thought to be selective and relatively safe on beneficials except for predatory mites (Buckelew 2002).

Insecticide developments and new registrations in recent years have been impressive. New chemical classes and modes of action are being discovered regularly. Our testing program insures that growers are armed with locally-relevant, objective information on the impact of these compounds in our agroecosystem. Further, we are able to advise industry cooperators about the efficacy of their candidate compounds on species that are not common in the remainder of the cotton belt (e.g., whiteflies, *Lygus hesperus*, and pink bollworm). This helps us secure compounds for uses that otherwise might not be known. This year we examined the neonicotinoid class of chemistry in detail and found variable abilities to control whiteflies and no impact on *Lygus* control. In fact, one candidate, dinotefuran may be negatively impacting key predators that otherwise help to mitigate *Lygus* populations. For whiteflies, Intruder is the best performing neonicotinoid; however, our guidelines still support the usage of the IGRs, Knack or Courier, prior to the use of a neonicotinoid in the majority of cases. This is based in the IGRs superior selectivity and greater potential for long-term management of whiteflies (Naranjo et al. 2003, 2004).

We also tested four new classes of chemistry in 2003. One, spiromesifin (Oberon), shows excellent promise against whiteflies, and another, flonicamid, actually surpasses our *Lygus* control standards for the first time ever with any competing compound. These advances in insecticide discovery and testing will help stock the pest managers arsenal and secure our ability to control insects strategically, selectively, and economically in the future.

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Table 1. Treatment numbers and identities for the 2003 whitefly and *Lygus* chemical efficacy trial conducted at the Maricopa Agricultural Center (Maricopa, AZ). T1–T13 were tested for whitefly efficacy, T10–19 were tested for *Lygus* efficacy, and T10–13 were tested against both species but were only sprayed as needed for whitefly control. No. of sprays made are listed for the primary target for each treatment followed by other maintenance sprays as indicated.

Trt #	**Common Name**	**Rate (lb ai / A)**	**No. of Applications**	**Experimental or Trade Name**	**Chemical Class or Functional Group**	**Comments**
1	novaluron	0.05	5	Diamond	IGR	Whitefly test
2	novaluron	0.025	5	Diamond	IGR	Whitefly test
3	spiromesifin	0.110	2	Oberon	tetronic acid	Whitefly test
4	spiromesifin	0.125	2	Oberon	tetronic acid	Whitefly test
5	spiromesifin	0.133	2	Oberon	tetronic acid	Whitefly test; max. cotton rate
6	thiacloprid + Kinetic	0.094	3	Calypso	neonicotinoid	Whitefly test
7	cyfluthrin+imidacloprid	0.079	4	Leverage	pyrethroid + neonicotinoid	Whitefly test
8	secrecy	0.022	1	—	—	Whitefly test; 1 spray only
9	secrecy	0.045	1	—	—	Whitefly test; 1 spray only
10	dinotefuran	0.13	3	V10112	neonicotinoid	Whitefly test; Lygus evaluated
11	dinotefuran	0.18	3	V10112	neonicotinoid	Whitefly test; Lygus evaluated
12	dinotefuran	0.26	3	V10112	neonicotinoid	Whitefly test; Lygus evaluated
13	acetamiprid	0.1	2	Intruder+R-11	neonicotinoid	Whitefly test; Lygus evaluated
14	acetamiprid	0.1	5, 1	Intruder+R-11+Orthene	neonicotinoid + o.p.	Lygus test; whitefly evaluated
15	acetamiprid	0.1	5, 1	Intruder+R-11+Vydate	neonicotinoid + carbamate	Lygus test; whitefly evaluated
16	Whitefly Program	recommended	0*	Knack fb Courier fb Intruder	IGR	Lygus test check; WF standard
17	novaluron	0.1	1*	Diamond	IGR	Lygus test; 1 spray only
18	flonicamid	0.088	4*	F1785 + NIS (X-77)	pyridine carboxamide	Lygus test; new class
19	fipronil	0.05	5*	Regent	phenylpyrazole	Lygus test; reg. in Australia
0	UTC	—	0	—	—	Whitefly test check

*, treatments were oversprayed with whitefly maintenance sprays shown in the 'Whitefly Program'.

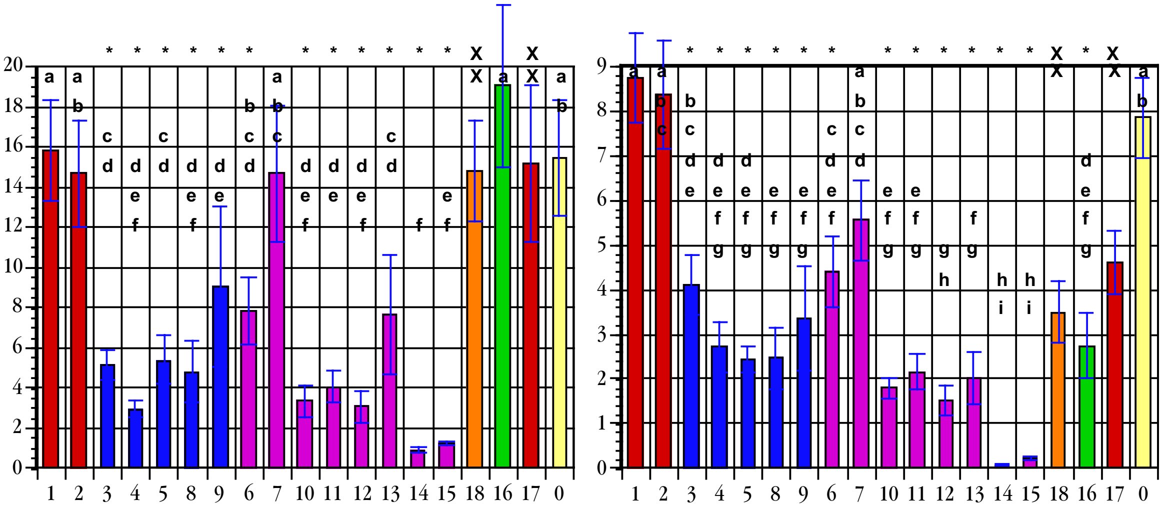

Figure 1 (left) and 2 (right). Seasonal average levels of whitefly eggs (left) or small nymphs (right) per 3.88 cm^2 leaf disk, including six dates: 8/13, 8/20, 8/26, 9/3, 9/10, 9/18. Total number of whitefly sprays were as follows: T8–9, 17: 1 spray; T3–5, 13: 2 sprays; T6, 10–12, 16: 3 sprays; T7, 18: 4 sprays; T1–2, 14–15: 5 sprays. T14–15, 17–19 sprays were made as needed for *Lygus* bug control but evaluated for whitefly levels, while the remainder were sprayed only as needed for whitefly control. T16–19 were sprayed with the IGR program; T17 and 18 (X) were not sampled on every date and therefore excluded from all seasonal analyses. T0 is the untreated check. Red bars indicate a new IGR; blue bars are novel whitefly chemistries; purple bars are neonicotinoids; orange bar is a novel *Lygus* chemistry; green bar is the whitefly IGR control program. Bars sharing a same letter are not significantly different from one another (Tukey's HSD, $P < 0.05$). Bars bearing an asterisk (*) are significantly different from the untreated check (T0) (Dunnett's T, $P < 0.05$).

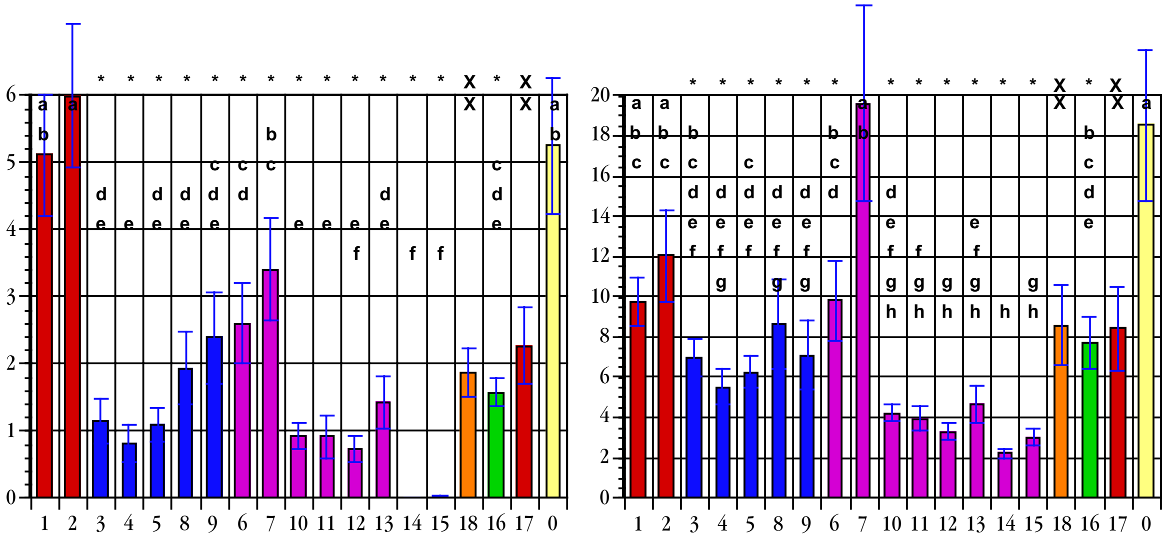

Figure 3 (left) and 4 (right). Seasonal average levels of whitefly large nymphs (left) per 3.88 cm^2 leaf disk or adults per leaf (right), including six dates: 8/13, 8/20, 8/26, 9/3, 9/10, 9/18. See Figure 1 and 2 for complete treatment and other chart details.

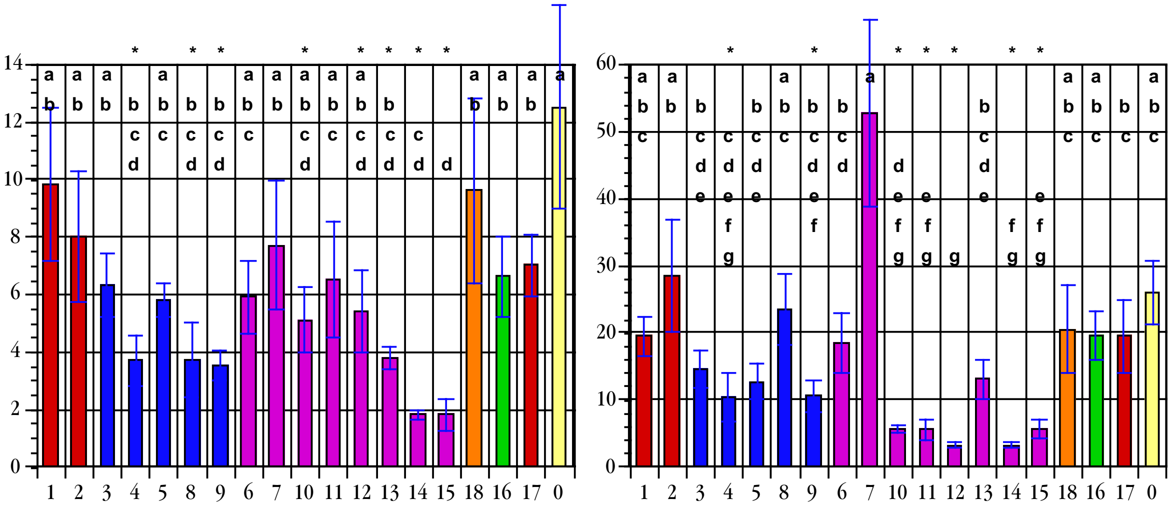

Figure 5 (left) and 6 (right). Average levels of whitefly adults per leaf for 3 September (left) or 10 September (right). Number of whitefly sprays and days after treatment (DAT) as follows (left for 9/3): T3–6, 8–13: 29DAT; T7: 6DAT2; T1–2: 6DAT3; T18: 13DAT3; T14–15: 6DAT4; and (right for 9/10): T8–9, 13: 36DAT; T3–6, 10–12, 16: 6DAT2; T7: 6DAT3; T1–2: 6DAT4; T18: 6DAT4; T14–15: 6DAT5. T14–15, 17–19 sprays were made as needed for *Lygus* bug control but evaluated for whitefly levels, while the remainder were sprayed only as needed for whitefly control. T16–18 were sprayed with the IGR program. T0 is the untreated check. Red bars indicate a new IGR; blue bars are novel whitefly chemistries; purple bars are neonicotinoids; orange bar is a novel *Lygus* chemistry; green bar is the whitefly IGR control program. Bars sharing a same letter are not significantly different from one another (Tukey's HSD, P < 0.05). Bars bearing an asterisk (*) are significantly different from the untreated check (T0) (Dunnett's T, P < 0.05).

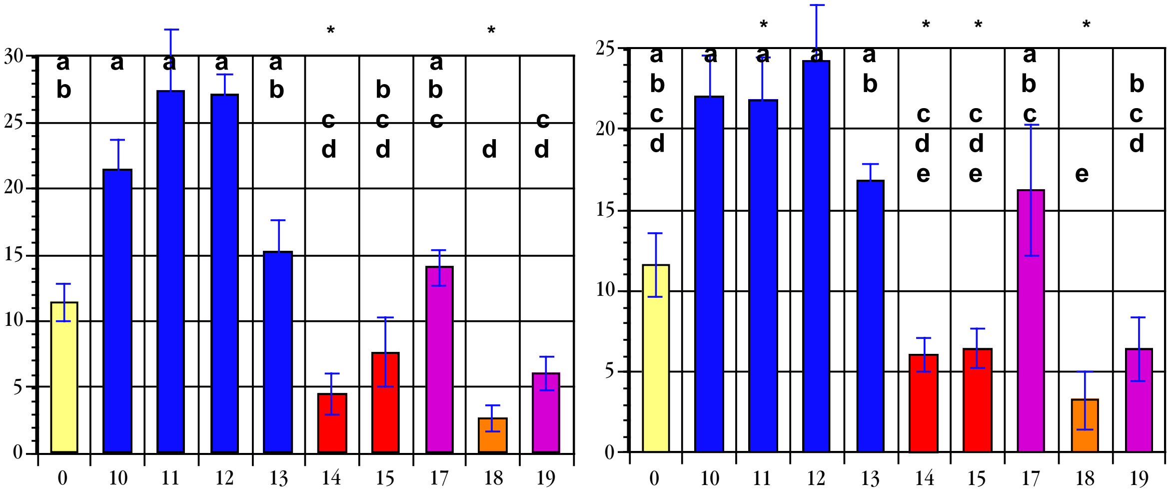

Figure 7 (left) and 8 (right). Seasonal average levels of *Lygus* small nymphs (left) and large nymphs (right) per 100 sweeps, including five dates: 8/20, 8/26, 9/3, 9/10, 9/18. Total number of *Lygus* sprays were as follows: T14, 15, 19: 5 sprays; T18: 4 sprays; T10–12: 3 sprays; T13: 2 sprays; T17: 1 spray. T10–13 sprays were made as needed for whitefly control but evaluated for *Lygus* levels, while the remainder were sprayed only as needed for *Lygus* control. T16–19 were sprayed with the IGR program for maintenance control of whiteflies. T0 is the untreated check. Blue bars are neonicotinoids; red bars are Intruder mixtures with Orthene or Vydate; purple and orange bars are novel *Lygus* chemistries. Bars sharing a same letter are not significantly different from one another (Tukey's HSD, P < 0.05). Bars bearing an asterisk (*) are significantly different from the untreated check (T0) (Dunnett's T, P < 0.05).

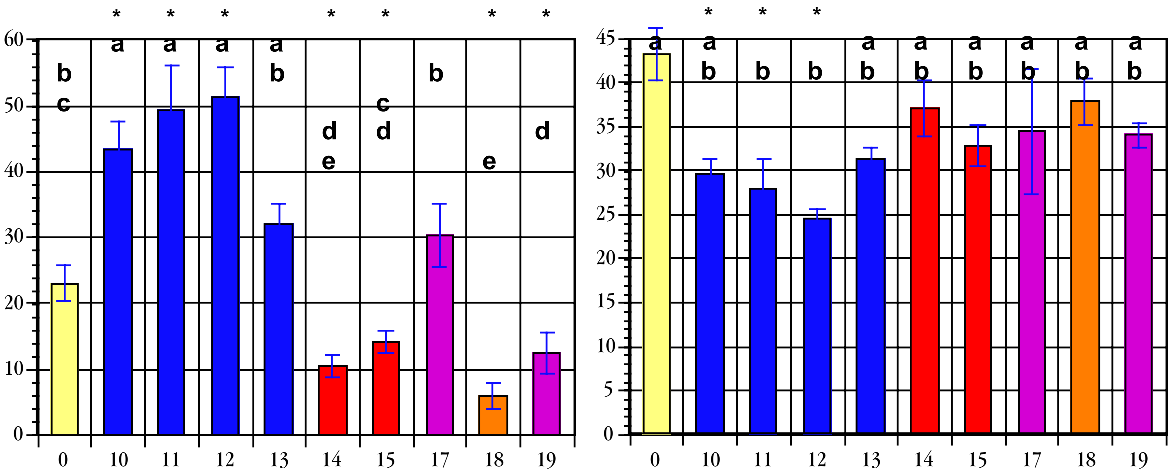

Figure 9 (left) and 10 (right). Seasonal average levels of all *Lygus* nymphs (left) and adults (right) per 100 sweeps, including five dates: 8/20, 8/26, 9/3, 9/10, 9/18. Total number of *Lygus* sprays were as follows: T14, 15, 19: 5 sprays; T18: 4 sprays; T10–12: 3 sprays; T13: 2 sprays; T17: 1 spray. T10–13 sprays were made as needed for whitefly control but evaluated for *Lygus* levels, while the remainder were sprayed only as needed for *Lygus* control. T16–19 were sprayed with the IGR program for maintenance control of whiteflies. T0 is the untreated check. Blue bars are neonicotinoids; red bars are Intruder mixtures with Orthene or Vydate; purple and orange bars are novel *Lygus* chemistries. Bars sharing a same letter are not significantly different from one another (Tukey's HSD, P < 0.05). Bars bearing an asterisk (*) are significantly different from the untreated check (T0) (Dunnett's T, P < 0.05).

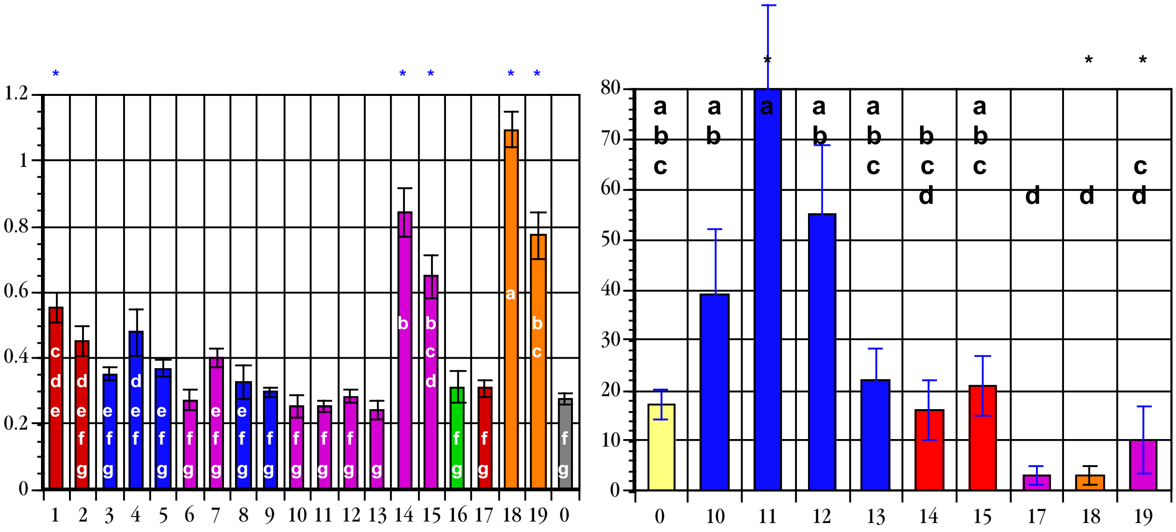

Figure 11 (left) and 12 (right). Average yields in bales per acre (left) and number of *Lygus* nymphs per 100 sweeps on 20 August (right). Number of *Lygus* sprays and days after treatment (DAT) for 8/26 (right) as follows: 7DAT; T10–13: 15DAT. T10–13 sprays were made as needed for whitefly control but evaluated for *Lygus* levels, while the remainder were sprayed only as needed for *Lygus* control. T16–19 were sprayed with the IGR program for maintenance control of whiteflies. T0 is the untreated whitefly check; T16 is the untreated *Lygus* check. Bars sharing a same letter are not significantly different from one another (Tukey's HSD, P < 0.05). Bars bearing an asterisk (*) are significantly different from the untreated check (T0) (Dunnett's T, P < 0.05).