

# Evaluation of Chemical Controls of *Lygus hesperus* in Arizona

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## Abstract

When other means fail to avoid damaging levels of an insect pest population, chemical control becomes necessary. Chemical control is a variable farm input which should be optimized to reduce economic damage by the pest while maximizing profit and minimizing exposure to secondary pest outbreaks, pest resurgence, and risks of insecticide resistance. To best balance these needs, a grower or PCA needs the best information possible for selecting and timing chemical controls. This study examines the array of *Lygus* chemical control options currently available as well as experimental compounds that may or may not be available in the future. While identifying the best chemical controls is the major objective of this study, insights into proper timing and duration of control are also discussed. In short, there are few, yet effective, *Lygus* insecticides available to growers currently. However, with proper rates and timing, significant yield protection can be achieved with Orthene® or Vydate®. To a lesser extent, Thiodan® (endosulfan) was also effective against *Lygus*, though higher rates than used in this study may be necessary to achieve acceptable control. The use of mixtures did not enhance control of *Lygus* over our two standards (Orthene or Vydate). Newer compounds were also studied; however, Mirids (plant bugs) are not worldwide targets for development by the agrochemical industry. Thus, most new compounds are effective on some other primary pest (e.g., whiteflies, boll weevil, thrips, aphids), and control of *Lygus* is merely a potential collateral benefit. Of these, the chloronicotinyls (e.g., Provado®, Actara®) were not practically effective against *Lygus hesperus*, in spite of their existing or pending labelling. Their labels are based on demonstrated efficacy against a related species present in cotton outside of the West (*Lygus lineolaris*). One compound shows excellent promise as a *Lygus* control agent, Regent® (fipronil). Under development by Rhône-Poulenc, this insecticide provides as good or better protection against *Lygus* than our best materials. In a system demanding multiple applications to control chronic *Lygus* populations, Regent could be key to the development of a sustainable use strategy that does not over rely on any single chemical class. None of the insecticides tested significantly controlled adult *Lygus*, except after repeated use and time. Even then, this effect was likely the result of generational control of the nymphal stage which thus produced fewer adults over time. Nymphal control was excellent for Orthene, Vydate, and Regent. Yields were up to five times higher in the best treatments relative to the untreated control. Other effects were also documented for the best treatments which have additional positive impact on grower profitability: shorter plants (better defoliation), higher lint turnouts, less gin trash, and a lower seed index.

## Introduction

*Lygus* is the number one cotton insect pest in Arizona (Ellsworth et al., *this volume*; Williams 1999). While its status was exaggerated in 1998 by the diminutive roles of pink bollworm and whiteflies and the presence of key source crops in some parts of the state, *Lygus* bugs have been a perennial reducer of Arizona cotton grower profitability (Table 1; Head 1991–1993; Williams 1994–1999). Direct losses to and control costs for this pest have been in the tens of millions of dollars for several years.

Significant advances have been made in control technologies for whiteflies (e.g., insect growth regulators) and pink bollworm (Bt cotton); however, similar gains have not been made with respect to *Lygus*. On the contrary, the advances made in other cotton pest systems have exposed this pest as a major threat to grower profitability (e.g., Ellsworth & Naranjo, *this volume*). At the same time, growers are searching for production alternatives, some of which can potentially alter the crop ecology of the local production community. These changes, if not properly managed or planned for, can lead to an even greater supply of immigrating *Lygus* adult populations into cotton.

Insecticide development has experienced a renaissance since the relative dearth of new chemistries developed after the discovery and development of synthetic pyrethroids during the decade of the 80's. This proliferation of new chemistries with novel modes of action presents growers with a dizzying number of insecticidal options (see Palumbo, 1997). While this diversity is highly desirable, growers and PCAs must become familiar with many new facets of chemical control, not the least of which is the much narrower spectrum of control common to many of these novel insecticides. This diversity comes at a cost, too. Most new insecticides cost significantly more than the materials they are intended to replace. Again, the replacements tend not to control as wide a range of pests as the older, broader-spectrum chemistries.

There is a more insidious, hidden cost of this boon in new insecticide development. That is, companies are forced to develop insecticides for specific targets of world-wide importance. While this has always been true, it is further exaggerated by the relatively narrow spectrum of the newer compounds. In other words, sales of insecticides for regionally “minor” pests do not provide the economic incentives needed by companies for discovery and development. In the case of *Lygus* bugs, they are members of the insect family Miridae. This family of insects is principally plant-feeding; however, world-wide and in key crop markets (rice, corn, potatoes, cotton), there are no major insect pests that drive the development of insecticides. Plant bugs in U.S. cotton are significant pests, but currently no companies have them as a target of their primary screens. Thus, new insecticides for plant bugs will likely only be the result of development for other, unrelated insect targets. Furthermore, even in the U.S. cotton market, our principal plant bug species, *Lygus hesperus*, is different from the one common to cotton east of Arizona (*Lygus lineolaris*). Indications are that the control dynamics for our *Lygus* species is far more difficult than for the eastern species. So even new insecticides with “reported” activity against plant bugs must be thoroughly tested in Arizona.

The objective of this study was to thoroughly evaluate old and new chemistries for the control of *Lygus hesperus* in cotton. In the course of these evaluations, additional insights into the residual, timing, and profitability of each are provided. Furthermore, the direct and indirect damage potential of this species of plant bugs is explored.

## Methods

Two small plot (12 rows by 36.5 ft; 0.033 A) experiments were conducted on the research farm of the Maricopa Agricultural Center (MAC) in 1998. The two tests were planted in adjacent borders on 1 April with NuCOTN 33b and watered-up on 2 May. Both consisted of 12 treatments, including and untreated check, and 4 replications. Each replicate was separated by a two-row border, and plots were separated by 7-ft alleys.

Each test was comprised of various chemical control treatments directed at and timed for either *Lygus hesperus* or whitefly populations. Both insects were monitored in each test at least weekly just prior to and after treatment initiation. All applications were made using a modified John Deere Hi-Cycle Model 600A at 20 GPA. In the “*Lygus*” test, applications were initiated on 21 July after *Lygus* had reached threshold levels (Ellsworth & Diehl 1998) for at least

one week. This constitutes a later than commercially-acceptable start, but does provide for excellent product comparisons. Treatments were re-sprayed on 28 July, 4 August, 18 August, and 26 August, except for the “Program” treatment which was skipped on 4 and 26 August (Table 2). In the “Whitefly” test, applications were initiated on 30 July for the Provado treatments only (Table 3). The remainder of the test was sprayed on 7 August, about 3 weeks after the field reached threshold levels for *Lygus*, because timing was based on whitefly densities. All treatments were re-sprayed on 26 August, except for the two formulations of Knack® which were never re-sprayed. Thus, depending on the insecticide, applications were made 1, 2 or 3 times in this test. The untreated check (UTC) was never sprayed in either test.

The treatment list for the “Lygus” test appears in Table 2. Orthene 90S or Vydate C-LV served as the commercial standards in this test. Orthene 97 is an alternative formulation of acephate, a dustless, extruded granule, which should be available in limited supply in 1999. Regent is a phenylpyrazole, a new unregistered chemistry under development for boll weevil, thrips, and plant bug control in cotton (see Ellsworth et al., *this volume*). C293343 (Actara®) is a chloronicotinyl under development for whitefly, aphid, and plant bug control by Novartis. Two rates were tested and can be compared to the other chloronicotinyl, imidacloprid (i.e., Provado®), in a pre-mix with Baythroid® which is marketed by Bayer as Legend®. This pyrethroid mixture (Legend) can be further compared to the other pyrethroid mixture, Mustang® + Thiodan®, which, in turn, may be compared to the non-pyrethroid mixture, Lannate® + Thiodan. Both endosulfan (Thiodan) mixtures can be compared to Thiodan alone. A “Program” treatment was established to 1) reduce costs by reducing the number of treatments, and 2) evaluate rotations as a potential, efficacy-sustaining tactic. The Program was sprayed a total of 3 times versus 5 times for the others. The first application was with Orthene 97, followed by Vydate C-LV, followed 21 days later by Regent.

The treatment list for the “Whitefly” test appears in Table 3. Orthene 90S with Danitol® served as the *Lygus* standard for this test. Two formulations of Knack were compared. Applaud® followed by Knack served as an IGR whitefly standard and can be compared to Applaud + Phaser® (endosulfan) used twice. The chloronicotinyl, C293343, was tested at 2 rates as above and may be compared to the two Provado treatments, one followed by Applaud and the other followed by Knack. One Provado application preceded all other treatment regimes (30 July) to reflect an anticipatory strategy (mainly for whiteflies); however, *Lygus* densities were already very high in this test. Fulfill® is a novel, unregistered chemistry (pyridine azomethine) under development by Novartis for aphid and whitefly control. The only adjuvant used in any of these tests was Silwet® and only in the Fulfill treatment. ‘XVL’ is an experimental compound.

Standard population measurements were made for *Lygus* bugs (small nymphs, large nymphs, and adults) (Ellsworth et al. 1998b, *this volume*). A total of 25 sweeps per plot were collected, bagged and frozen for laboratory sorting. All data are reported, untransformed, per 100 sweeps.

Plant heights were measured at harvest from 3 representative plants from the centers of each plot. Three plants were selected at random and removed from each of several selected treatments in one replicate for later processing. First position bolls from the removed plants were hand-harvested and hand-processed for number of seeds, motes, carpels, and raw cotton, seed, and lint weights on a per boll basis.

Seed cotton was machine-picked from two, 2-row subsamples and weighed. Grab samples were selected at random from each subsample and ginned in a one third, commercial-scale research gin. Lint and seed fractions were collected and weighed, and turnouts calculated for each subsample. Individual turnouts were used to derive yield estimates for each plot and reported as no. of 480 lb bales / A. Statistics were performed on normalized data, where possible, including ANOVA with appropriate, pre-planned, orthogonal contrasts using JMP® Software (SAS, 1995).

## Results & Discussion

*Lygus* populations are a chronic, perennial problem at the specific location of these trials on MAC; however, the 1998 season was atypical in several ways. Crop development was delayed relative to normal, and the fruiting cycle was pushed later into a period of monsoonal conditions and greater *Lygus* pressure. This was in severe contrast to 1997 (see Ellsworth et al. 1998b) when production was early and prior to the onset of monsoonal conditions and damaging

insect populations. The densities of *Lygus* measured in these trials were not the highest experienced at MAC; however, the duration of infestation and the persistence of adults was far longer than had been experienced in the past (e.g., see Pacheco et al. 1998). Threshold levels of *Lygus* were reached on 14 July and did not return to sub-threshold levels until 17 September in the UTC. The persistent adult levels can be explained at least in part by the over abundance of spring host material and then the presence of burgeoning populations in neighboring seed alfalfa fields.

### “*Lygus*” Trial

The results of the *Lygus* population dynamics in this trial are presented in figures 1–6. The total *Lygus* numbers reflect user experiences in the field all over the state. Treatments for *Lygus* work, however, control is not dramatic when viewed as total numbers depending on the density of adults. Furthermore, none of the products tested provided for good knockdown effects (2 DAT) (fig. 1). Total numbers 6 DAT2 reflect the frustration that many PCAs feel when total numbers are only barely half those measured prior to treating. Nonetheless, total numbers were lowest in the Regent, Orthene, and Vydate treatments (including the Program) (fig. 1). The chloronicotinyls (C293343 & Legend) did not lower total numbers significantly from the UTC season-long ( $P > 0.05$ ), except for C100 6 DAT3 (fig. 1). This, too, was the only date that the higher rate of C293343 was significantly better than Legend ( $P < 0.05$ ). The Thiodan and Thiodan mixtures provided marginal reductions in total numbers on a few dates (fig. 1), but were never significantly different from each other ( $P > 0.05$ ) except on one date. On 8 DAT5, the Lannate + Thiodan mixture had fewer total *Lygus* than the Thiodan alone treatment ( $P < 0.01$ ) and on 21 DAT5 Mustang + Thiodan had fewer total *Lygus* than Thiodan ( $P < 0.05$ ); however, the efficiency of sweeping declined precipitously late season due to the excessive height of the plants (over 6 ft tall). Regent provided excellent control throughout the test and was the best performer 6 DAT2, 13 DAT3, and 6 DAT4 (fig. 1). Trends, in general, would indicate that the Orthene, Vydate and Regent treatments had at least 13 days residual (see 13 DAT3; fig. 1).

In fig. 2, the source of frustration among growers becomes apparent. Adult levels are largely refractory to most insecticides. There were few significant differences noted season-long, including in comparison to the UTC. Adult levels were more or less static throughout the entire period in the range of about 20 / 100 sweeps (UTC: 18–44 / 100 sweeps). There are apparently few direct effects on adults (see 2 DAT, 6 DAT2, 13 DAT3; fig. 2). There were significant differences from the check at 6 DAT3 which is 20 days after initial treatment. *Lygus* nymphal development takes about 20 days under summer conditions (Diehl et al. 1998). Thus, this reduction is more likely the result of the generational control of nymphs which therefore yield fewer adults, and not as a result of direct toxic effect on existing adult populations. The chloronicotinyls (C293343 & Legend) did not lower adult numbers significantly from the UTC season-long ( $P > 0.05$ ), except for C100 6 DAT3 (and C75 8 DAT5) (fig. 2). This, too, was the only date that the higher rate of C293343 was significantly better than its lower rate as well as Legend ( $P < 0.05$ ). Regent had the lowest number of adults 6 DAT4; however, starting at about this same time, we noted significant infestations of mites and signs of premature defoliation. Regent plots were defoliated by the last evaluation and were therefore less likely to harbor or attract adults.

Control of nymphs appears to be key to understanding the relative efficacy and value of these compounds to *Lygus* control (fig. 3–6). Initial knockdown (2 DAT) was still not impressive, but by 6 DAT2 the best treatments drove levels down to less than 10% of the UTC (Vydate, Regent, and all Orthene treatments; fig. 3). The Thiodan treatments also showed efficacy; however, only those same ‘best’ treatments above lowered total nymph levels to zero 6 DAT3 and continued to hold nymphal levels to less than 10% of the UTC 13 DAT3. By the fourth spray (6 DAT4), the Vydate treatment was less efficacious which might reflect tolerances building up in this repeated regime. The chloronicotinyls were largely ineffective.

New insight into the duration of control or residual relative to *Lygus* nymphs can be seen in figure 6. For our best treatments (Orthene, Vydate, Regent), we can compare the impact of repeated use of these compounds relative to the Program which was sprayed two less times and with a rotation of the three compounds above. After the first application, nymphal levels declined, but by the second application, all four regimes reduced nymphal levels to near zero. The third application was skipped in the Program, yet all four regimes continued to suppress nymphal levels to zero (fig. 6; also see 6 DAT3, fig. 3). Thus, the Program which had been sprayed once each with Orthene 97 and Vydate was still holding nymphs to zero 13 DAT2, no different from the other 3 regimes 6 DAT3. By the next evaluation (20 DAT2 & 13 DAT3, respectively), the Program experienced a huge increase in nymph levels, most of which were small nymphs (see next sections), while the 3 repeated regimes continued to maintain control. Thus, the residual for nymphal

control appears to be between 13 and 20 days for these compounds. The fourth spray in the 3 repeated regimes did not appear to provide any additional control benefit (fig. 6 & 3, 6 DAT4). In fact, the Vydate repeated regime actually had an increase in the number of nymphs, signalling the possible loss of efficacy of this compound under these conditions. The Regent spray within the Program (6 DAT3), however, showed a marked decrease in the total nymph numbers relative to precount levels. Thus the advantage of a rotated program with three different products may have provided additional efficacy-sustaining benefits. This also shows the importance of the need for an additional mode of action, such as Regent, when *Lygus* levels are chronically over threshold. Repeated use of either Orthene or Vydate (or Regent) would appear to be poorly advised beyond two applications.

Large nymphs (instars 4–5) develop in about 7 days after egg hatch and are likely responsible for the majority of damage caused by the nymphal stage of this insect (Diehl et al. 1998). Their numbers reflected the same trends noted above for the total nymphs (fig. 4). The core set of performing treatments continued to show the best results here (Regent, Vydate, and the Orthene treatments). The chloronicotinyls and Thiodan and its combinations were largely ineffective. On two occasions (13 DAT3 & 15 DAT5), large nymph levels were significantly higher in some of these same treatments. The mechanism for this ostensible resurgence is unknown.

Small nymphs (instars 1–3) hatch from eggs in about 7 days and may play only a minor role in the damage caused by this stage (Diehl et al. 1998). There were relatively low numbers of small nymphs detected season-long (fig. 5) which was related, in part, to the difficulty in retrieving and counting the smallest nymphs from sweep samples. The same treatments effective against large nymphs and all nymphs were effective here (Regent, Vydate, and the Orthene treatments). Small nymph levels can signal the end of a control period and/or the beginning of a new egg hatch (e.g., 13 DAT3, fig. 5). The huge explosion of small nymph levels in the Program regime was likely due to the extended period without spraying (see 20 DAT2, fig. 5). This re-enforces the conclusion that nymphal control residual for these more effective compounds tends to be between 13 and 20 days in duration.

### “Whitefly” Trial

In this test, the initial timing of insecticide use was more related to whitefly levels than *Lygus* levels. Thus, the initiation of applications was well after the onset of damaging levels of *Lygus*. This fact alone impacted the “success” of the *Lygus* control program in this trial versus the one above. Most treatments were applied twice. The two Knack formulations were applied once, and the Provado regimes were timed one week before the general test for a total of 3 applications. Results of these treatments on *Lygus* populations dynamics are depicted in figures 7–9.

Populations were very high prior to the first sprays of Provado (ca. 45 total *Lygus* / 100 sweeps; fig. 7). Provado did not significantly lower total numbers after 1 or 2 sprays (6 DAT, 6 DAT2, 11 DAT2, 19 DAT2; fig. 7). The other chloronicotinyl tested, C293343, lowered total numbers in one or the other rates used in two of the post-treatment evaluations (6 DAT, 19 DAT; fig. 7). Lowering of total numbers was not apparent until 19 DAT; however, even then the effect was slight (no better than 50%) and included the two cotton IGRs, Applaud and Knack, which have no known direct effect on *Lygus* control. Danitol + Orthene, which served as this test’s standard, lowered numbers below threshold 11 DAT; however, still not significantly lower than the UTC.

Adult numbers were very heavy throughout most of the test for most of the season (> 20 / 100 sweeps; fig. 8). Like the first test, no insecticide provided long or short term control of adults. Some significant reductions were noted at 19 DAT, suggesting once again that adult suppression was more related to the control of immature stages. Only Danitol + Orthene was numerically lower than the UTC in every evaluation.

Control of nymphs tends to be the best indicator of *Lygus* insecticide efficacy. However in this trial, there were overwhelming numbers of nymphs present from the beginning, and the rank condition of the plants made it difficult to spray the crop efficiently. Thus, there were very few significant effects detected (fig. 9). By 8 DAT2, Applaud + Phaser had the least number of nymphs present.

In general, this test demonstrates that a late start with fewer sprays is not very different from not spraying at all, even when using proven chemistry like Orthene. None of the insecticides provided satisfactory control of *Lygus* in this trial. Though most are principally targeted for the control of other pests (chloronicotinyls for aphids and whiteflies; IGRs for whiteflies; Fulfill for sucking pests), Orthene at the full rate and Phaser at the half rate did not provide

adequate control when used in a rescue strategy. Timing, therefore, is critical to the control of this pest.

### Yield and Other Effects on the Plant

*Lygus* bugs attack the yield component directly, so unlike whiteflies, evaluation of *Lygus* control is readily evaluated by yield results as long as there are no other yield-limiting pests. The *Lygus* trial had ca. a 5-fold increase in yields of the best treatment over the UTC (fig. 10). The highest yielding treatments, Orthene 90S, Orthene 97 and Vydate CLV, were also among the most effective treatments based on *Lygus* population dynamics. Regent was next and not significantly different from Vydate. This slight reduction in yield is attributed to the premature defoliation of the Regent treatment by mites and not any lack of *Lygus* control. On the contrary, Regent control of *Lygus* appeared to be as good or superior to all other treatments. The Thiodan treatments yielded significantly more than the UTC, but substantially below the best treatments. The addition of Lannate or Mustang to Thiodan did not enhance yields ( $P > 0.10$ ). Legend had only marginally more yield than the UTC, and the other chloronicotinyl, C293343, was not significantly different from the UTC. The Program which received 2 fewer sprays than the other treatments actually out-yielded all but the most effective treatments. Thus, spraying with the right material three times is superior to using less effective compounds even five times. Had we timed the third spray of the Program one week sooner, we may not have seen any yield reduction below the best treatments.

In the best treatments, lint turnouts averaged 2% higher than the poorer performing *Lygus* treatments (fig. 11). The Regent, Program, Vydate and two Orthene treatments had significantly higher lint turnouts than the UTC ( $P < 0.05$ ). Furthermore, the Regent had the highest lint turnout of all treatments and was highly correlated with excellent *Lygus* control. The mechanism for this improvement in lint turnout is multi-dimensional and starts with the condition of the plants at harvest. Plants through most of the *Lygus* test had lost all height control. Plants measured at the conclusion of the trial revealed that the best *Lygus* control regimes had plants that were ca. 1 ft shorter than the less effective treatments (fig. 12). The height of the Program plants also indicated that we missed an important period of *Lygus* control. Only the top 5 *Lygus* control treatments were shorter than the UTC. This height control is likely related to the much heavier boll load in the better treatments. These plants may have had a water and N-status more conducive to clean defoliation. The taller plants of the poorer performing treatments tended to have more green leaves post-defoliation. The result was seedcotton that contained more trash much like that documented by Ellsworth & Naranjo (*this volume*). They also found that the seed index was also partially responsible for the differences seen in lint turnouts. Here, too, we found that the five best *Lygus* treatments had a significantly smaller seed index than the UTC (fig. 13). In other words, the seed produced under the better *Lygus* control regimes was smaller and lighter than seed produced under poor *Lygus* control regimes. This is likely related to the drastic changes in source-sink relationships between the two levels of *Lygus* control. With more bolls, the plant has more sinks to distribute the carbohydrates produced. Once again, the Regent treatment fared best with the smallest seed index (fig. 13). The relatively low seed index in the Program regime also indicated that good *Lygus* control was accomplished in this treatment. To our knowledge this is the first documented evidence (along with Ellsworth & Naranjo, *this volume*) that poor *Lygus* control has a cascading set of collateral, negative effects on these plant parameters (i.e., lint turnouts and seed index).

Yield effects were not as dramatic in the ‘Whitefly’ trial which reflects the relatively poor *Lygus* control in that trial. However, even relatively poorly-timed initiation of Danitol + Orthene applications resulted in over a 3-fold increase in yields over the UTC (fig. 14). Applaud + Phaser was the only other treatment that was significantly different from the UTC, yet still significantly lower than the best treatment. All other treatments did not out-yield the UTC significantly, including the two Provado regimes which were deployed one week sooner than the remaining treatments. Yields in this test were significantly lower than in the adjacent ‘*Lygus*’ trial. Nevertheless, Danitol + Orthene, sprayed late and only 2 times, was similar in yield to lesser materials used 5 times in the adjacent trial, though not as good as the Program (sprayed 3 times) or the best materials (Regent, Orthene, Vydate) used repeatedly. The relationship to lint turnouts continued (fig. 15). The two best *Lygus* treatments (Orthene with Danitol, and Phaser with Applaud) had the highest turnouts with only one exception. Turnouts, however, were substantially down overall from the ‘*Lygus*’ trial (fig. 11), also suggesting that protection against *Lygus* was less than complete in this trial.

### Recommendations

Under conditions of chronic, high level *Lygus* populations, chemical control is indeed required to protect against yield loss. Many compounds, new and old, qualify as being “*Lygus*-active”; however, few provide significant protection against loss. The best materials are those identified in prior studies (Ellsworth 1998a, b, c; Pacheco 1998; Ellsworth

& Diehl 1998; Ellsworth et al. 1998a, b; Ellsworth & Naranjo, *this volume*; Ellsworth et al., *this volume*). They are Orthene or Vydate, or Monitor (from prior studies). A lesser role may be played by endosulfan or dimethoate (from prior studies). Pyrethroids, other organophosphates or carbamates, or their mixtures do not provide protection superior to the best compounds identified above. With regards to new compounds (recently or soon to be registered), the chloronicotinyls (e.g., Provado and Actara) and Fulfill did not provide significant protection against *Lygus* damage in spite of their existing or future labelling for *Lygus* control or suppression. This labelling better reflects their activity against *Lygus lineolaris*, the principal species of cotton in the South. Only Regent (fipronil) under development by Rhône-Poulenc showed promise as a consistent *Lygus* control agent. Regent performed as well or better than our best, currently available compounds. Regent is a brand new mode of action which should complement our organophosphate (Orthene, Monitor) and carbamate (Vydate) options. A rotated program of these three classes of chemistry performed well with indications that tolerance was averted.

None of the compounds tested here or in the past provided excellent control of *Lygus* adults. The best performing treatments did provide excellent control of nymphs, and this appears to be closely related to yield protection. Thus, applications that are timed based on the presence of adults only are likely to result in unsatisfactory results, including higher input costs without concomitant increases in yield. Control residual for nymphs appeared to be between 13 and 20 days for our best compounds. At 21 days, the Program regime suffered large increases in small nymph numbers and a substantial reduction in yield. Furthermore, in the 'Whitefly' trial, initial applications delayed 3 weeks resulted in substantially lower yields even when using the best compounds. Thus, product choice, timing, and rotation appear to be key to the successful chemical control of this insect (Ellsworth 1998a–c). Rotation with a limited set of chemistry (OPs and carbamates) and chronic sources of immigrating *Lygus* appear to be formula for significant losses in susceptibility of our *Lygus* populations. By the fourth repeated application of our best materials, *Lygus* populations were not substantially reduced. However, with the addition of Regent as part of a rotational approach (i.e., the Program regime), we saw outstanding efficacy during this same period. Thus, it is imperative that growers gain access to this additional chemistry, especially in areas of chronic need, so that a sustainable use pattern can be achieved through the rational rotation of our best products (Orthene, Vydate, and Regent). Our current IRM recommendations suggest limiting the usage of any single active ingredient to no more than two uses per season. This recommendation appears to be prudent advice when selecting and using these products against *Lygus*.

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## Disclaimer

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Table 1. Arizona statewide average *Lygus* control and loss statistics (1990–1998). Columns in order are: the number of foliar sprays made to control *Lygus*; the costs of the *Lygus* foliar spray program; the percentage of the total foliar insect control costs that were dedicated to *Lygus* control; the loss associated with *Lygus* averaged over the entire state and in spite of controls; the percentage of the total insect losses that were as a result of *Lygus*; the amount of money lost in production alone to *Lygus* statewide (adapted from Head 1991–1993; Williams 1994–1999).

Year	Applications (No. / A)	Cost of Control (\$/A)	% of Total Insect Control	Yield Reduction (%)	% of Total Insect Losses	Crop Loss (\$ millions)
1990	1.90	17.10	15.0	0.95	15.8	2.9
1991	3.30	33.00	31.4	1.64	51.6	5.8
1992	0.50	5.00	4.1	0.12	1.2	0.3
1993	0.20	2.60	3.7	0.50	11.3	1.3
1994	1.20	14.40	10.4	4.81	45.5	10.6
1995	2.30	27.60	12.8	6.08	70.1	17.4
1996	1.26	25.25	22.7	4.75	47.5	16.2
1997	2.10	37.67	35.0	2.63	41.4	8.4
1998	2.76	55.20	53.4	7.00	78.3	16.4

Table 2. Treatment list of compounds used in the 1998 ‘*Lygus*’ small plot trial located at the Maricopa Agricultural Center. All treatments were made repeatedly for a total of 5 applications, except for the ‘Program.’ The Program consisted of only 3 sprays, skipping the 3rd and 5th applications of the others, with Orthene 97, followed by Vydate C-LV, and then followed by Regent at the rates indicated for those individual treatments. Regent and C293343 (a.k.a C75 & C100) (and Fulfill and XVL; see table 3) are not currently registered for use in cotton.

Compound	Rate (lb ai / A)	No. of Applications	Common Name	Chemical Class	Comments
Orthene 90S	1	5	acephate	organophosphate	<i>Lygus</i> control standard
Orthene 97	1	5	acephate	organophosphate	Alt. formulation of acephate
Vydate C-LV	1	5	oxamyl	carbamate	Alternative <i>Lygus</i> control standard
Regent	0.05	5	fipronil	phenylpyrazole	New mode of action; weevils, thrips
Thiodan	0.75	5	endosulfan	cyclodiene	For comparison to mixtures
Lannate + Thiodan	0.5 + 0.75	5	methomyl + ...	carbamate	Non-pyrethroid mixture
Mustang + Thiodan	0.05 + 0.75	5	z-cypermethrin + ...	pyrethroid	Pyrethroid mixture
Legend	3.75 fl. oz.	5	cyfluthrin + imidacloprid	pyrethroid + chloronicotinyl	Pyrethroid mixture
C293343H	0.089	5	thiomethoxam	chloronicotinyl	New product; aphids, whiteflies
C293343L	0.067	5	thiomethoxam	chloronicotinyl	"
Program	*	3	*	—	Rotated limited use of best materials
UTC	—	0	—	—	

Table 3. Treatment list of compounds used in the 1998 ‘Whitefly’ small plot trial located at the Maricopa Agricultural Center. Most treatment or regimes were made twice, except for the Provado and Knack treatments. The Provado treatments were initiated one week in advance of the general trial for a total of 3 sprays. Knack was sprayed once.

Compound	Rate (lb ai / A)	No. of Applications	Common Name	Chemical Class	Comments
Orthene + Danitol	1 + 0.2	2	acephate + fenpropathrin	organophosphate + pyrethroid	<i>Lygus</i> control standard
Applaud fb Knack	0.35, 0.054	1, 1	buprofezin fb pyriproxyfen	thiadiazine fb juvenoid	Whitefly control standard
Applaud + Phaser	0.35 + 0.75	2	buprofezin + endosulfan	thiadiazine + cyclodiene	IGR mixture
Knack 0.86E once	0.054	1	pyriproxyfen	juvenoid	IGR used once
Knack 2.9E once	0.054	1	pyriproxyfen	juvenoid	Alternative formulation of Knack
Provado fb Knack	0.047, 0.054	2, 1	imidacloprid fb ...	chloronicotinyl	Advanced use of Provado
Provado fb Applaud	0.047, 0.35	2, 1	imidacloprid fb ...	chloronicotinyl	Advanced use of Provado
C293343H	0.089	2	thiomethoxam	chloronicotinyl	New product; aphids, whiteflies
C293343L	0.067	2	thiomethoxam	chloronicotinyl	"
Fulfill + Silwet	0.094	2	pymetrozine + surfactant	pyridine azomethine	New mode of action; aphids, WFs
XVL		2		—	Experimental compound
UTC	—	0	—	—	

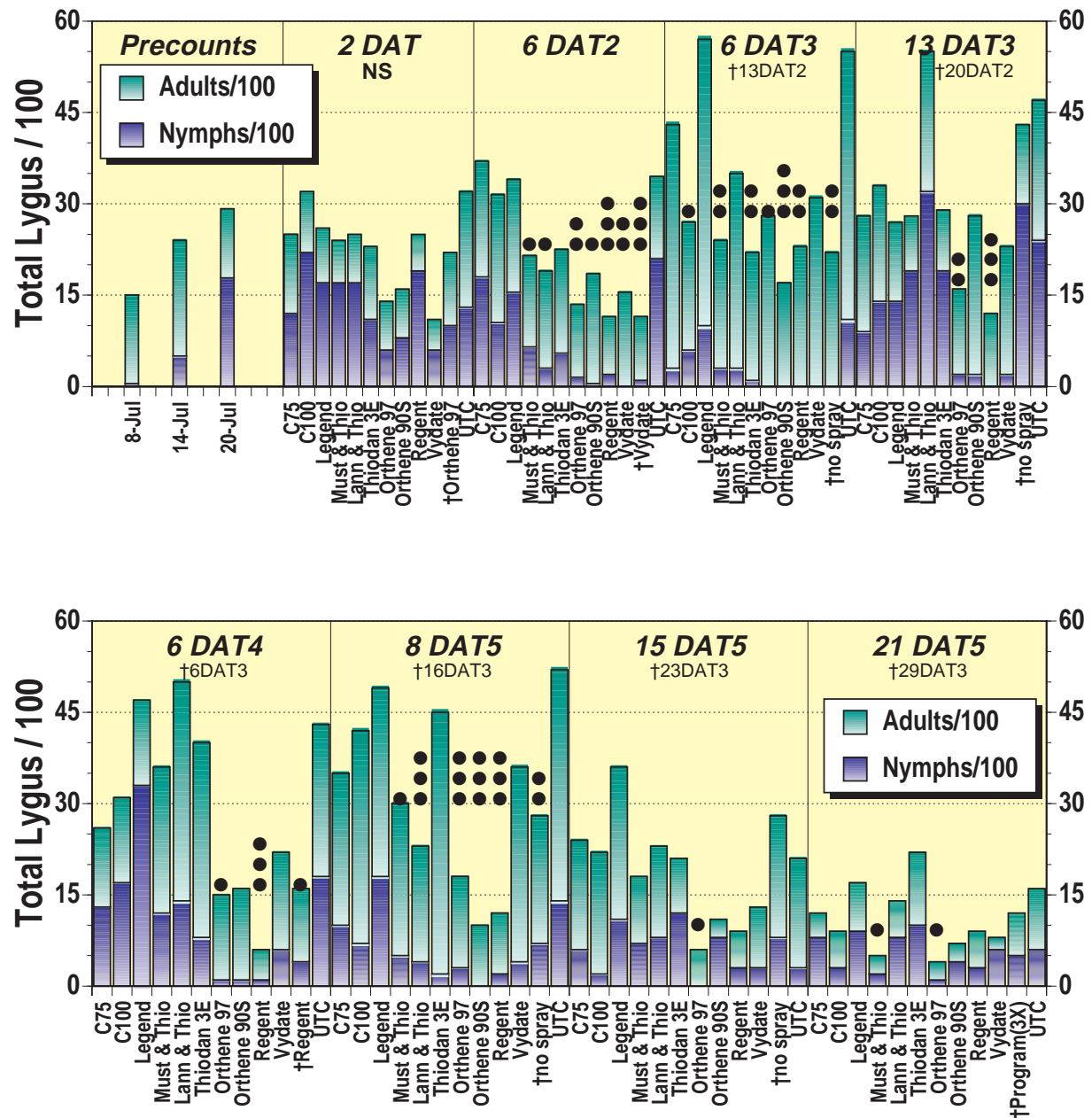


Figure 1. Total number of *Lygus* bugs per 100 sweeps in response to insecticides in a small plot trial, Maricopa, AZ. Sprays were made 7 days after reaching threshold (14 July) on 21 and 28 July, and 4, 18, and 26 August, except for the 'Program' which was skipped on the third and fifth sprays. See table 2 for treatment descriptions. Evaluations were made three times prior to and 1–3 times after each spray (DAT=days after treatment). Within an evaluation, treatments indicated with '•' are significantly different from the UTC by orthogonal contrasts (•:  $P < 0.05$ ; ••:  $P < 0.01$ ; •••:  $P < 0.001$ ). In general, Regent, Vydate and the two Orthene treatments including the Program provided the best control of *Lygus* numbers. UTC=Untreated Check. †=Program sprays and timing.

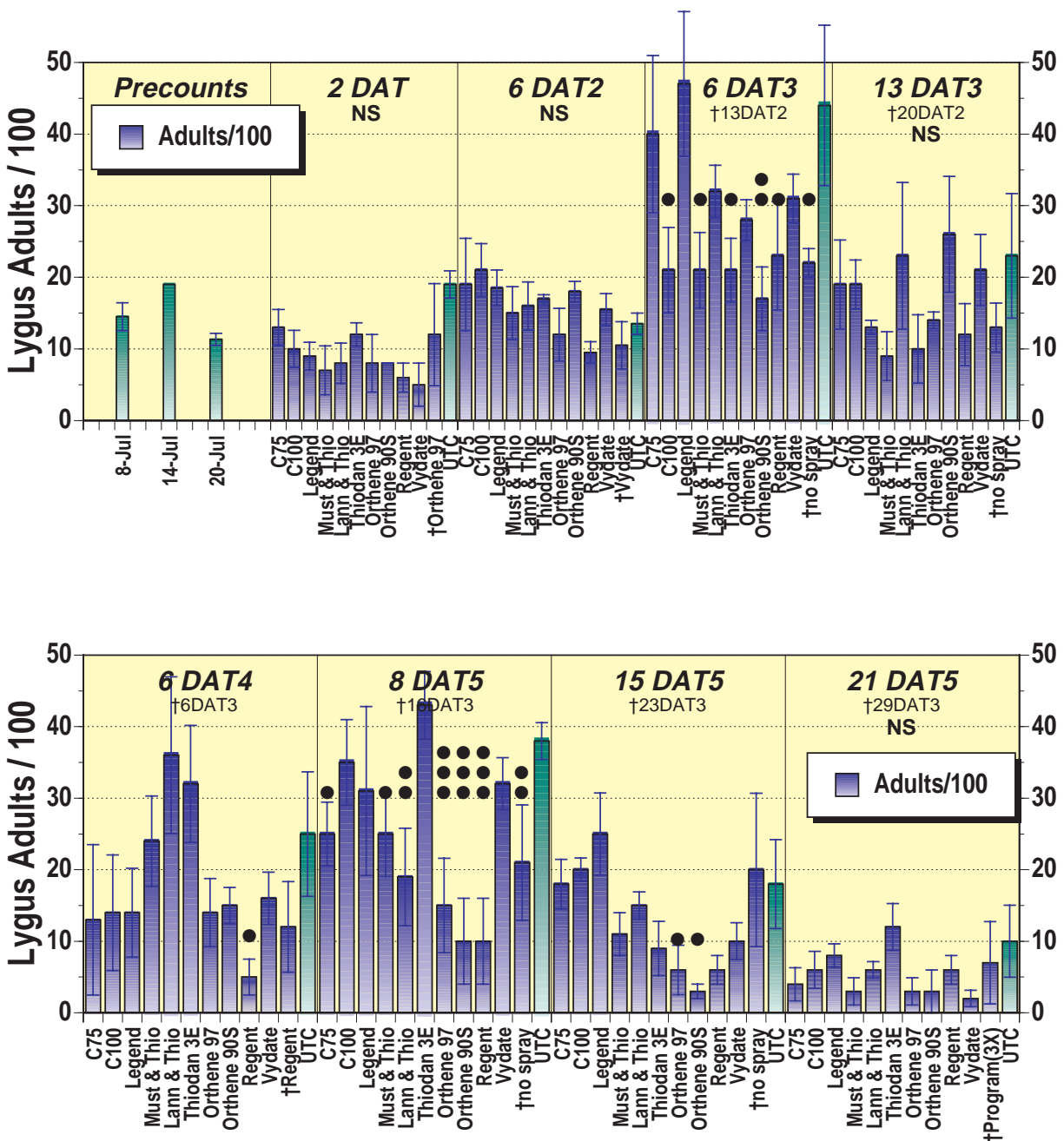


Figure 2. Number of *Lygus* adults per 100 sweeps ( $\pm$  SE) in response to insecticides in a small plot trial, Maricopa, AZ. Sprays were made 7 days after reaching threshold (14 July) on 21 and 28 July, and 4, 18, and 26 August, except for the 'Program' which was skipped on the third and fifth sprays. See table 2 for treatment descriptions. Evaluations were made three times prior to and 1–3 times after each spray (DAT=days after treatment). Within an evaluation, treatments indicated with '\*' are significantly different from the UTC by orthogonal contrasts (\*:  $P < 0.05$ ; \*\*:  $P < 0.01$ ; \*\*\*:  $P < 0.001$ ). In general, none of the insecticides tested provided reliable or direct control of the adults; however, lower adult numbers were sometimes found and were most likely related to control of nymphs over time. UTC=Untreated Check. †=Program sprays and timing.

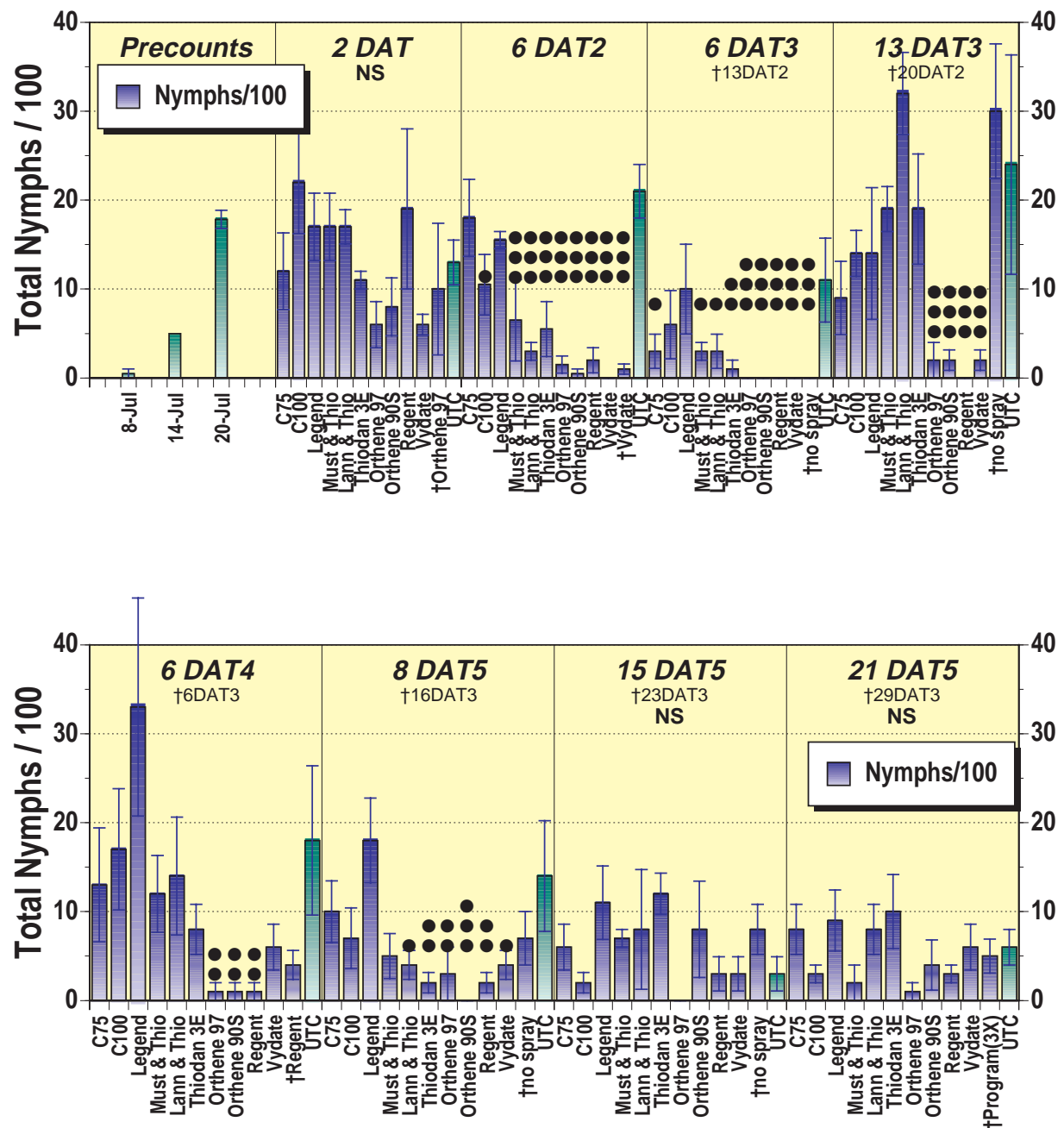


Figure 3. Number of *Lygus* nymphs per 100 sweeps ( $\pm$  SE) in response to insecticides in a small plot trial, Maricopa, AZ. Sprays were made 7 days after reaching threshold (14 July) on 21 and 28 July, and 4, 18, and 26 August, except for the 'Program' which was skipped on the third and fifth sprays. See table 2 for treatment descriptions. Evaluations were made three times prior to and 1–3 times after each spray (DAT=days after treatment). Within an evaluation, treatments indicated with '•' are significantly different from the UTC by orthogonal contrasts (•:  $P<0.05$ ; ••:  $P<0.01$ ; •••:  $P<0.001$ ). While reduction in nymph numbers was not immediate (2 DAT), control of nymphs was impressive with numbers as low as 0 for Regent, Vydate and the Orthene treatments (6 DAT3) including the Program (13 DAT2). UTC=Untreated Check. †=Program sprays and timing.

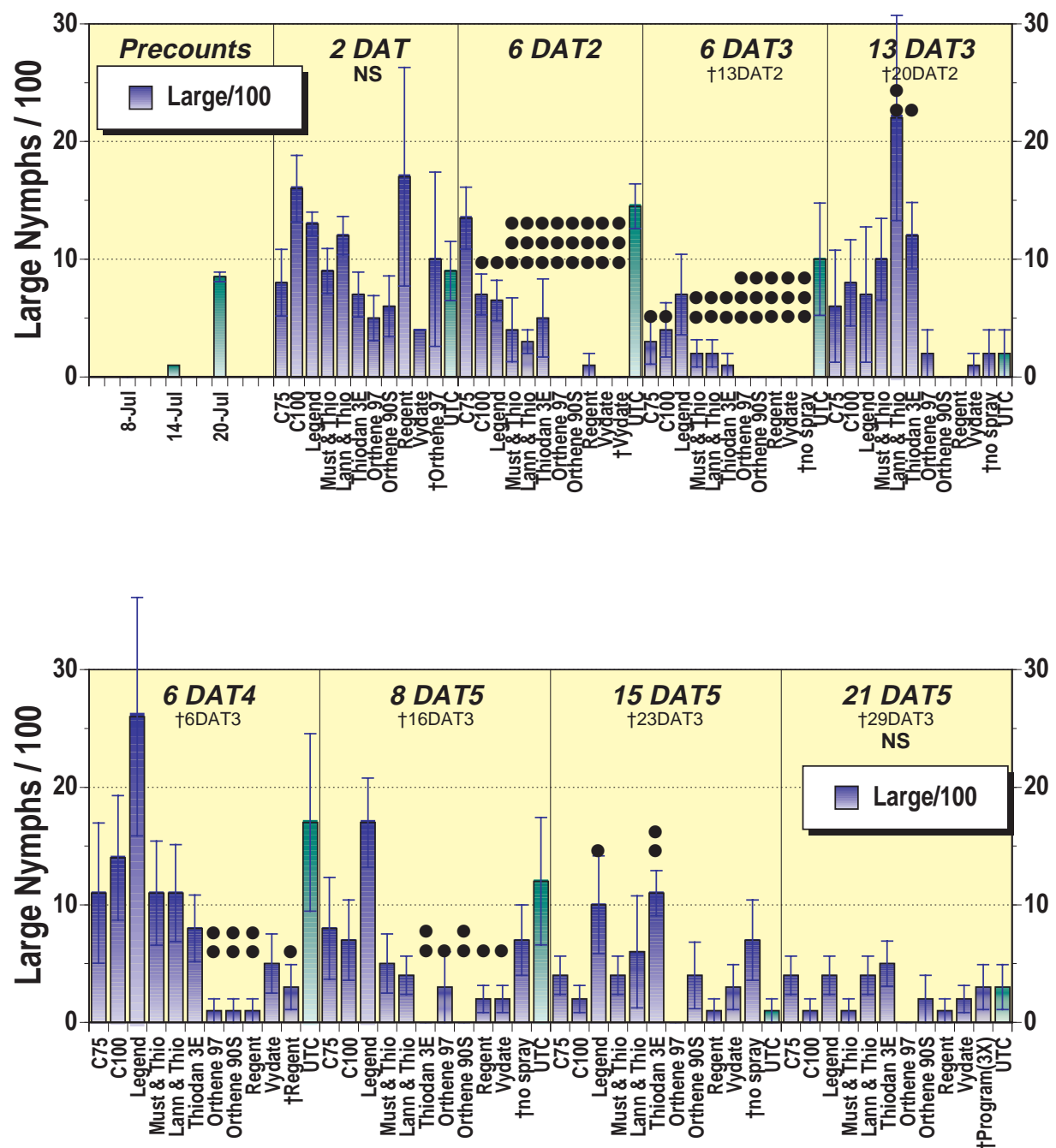


Figure 4. Number of *Lygus* large nymphs (instars 4–5) per 100 sweeps ( $\pm$  SE) in response to insecticides in a small plot trial, Maricopa, AZ. Sprays were made 7 days after reaching threshold (14 July) on 21 and 28 July, and 4, 18, and 26 August, except for the ‘Program’ which was skipped on the third and fifth sprays. See table 2 for treatment descriptions. Evaluations were made three times prior to and 1–3 times after each spray (DAT=days after treatment). Within an evaluation, treatments indicated with ‘•’ are significantly different from the UTC by orthogonal contrasts (•:  $P<0.05$ ; ••:  $P<0.01$ ; •••:  $P<0.001$ ). Large nymph control, while not immediate (2 DAT), was excellent, especially for Regent, Vydate, and the Orthene treatments including the Program. UTC=Untreated Check. †=Program sprays and timing.

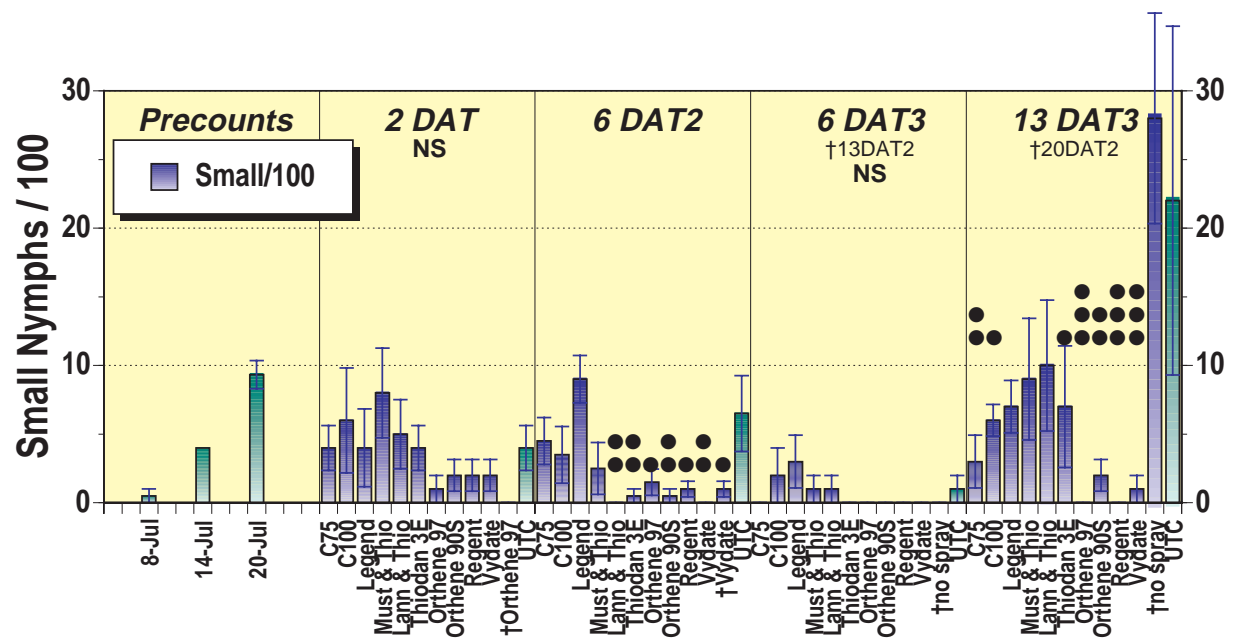


Figure 5. Number of *Lygus* small nymphs (instars 1–3) per 100 sweeps ( $\pm$  SE) in response to insecticides in a small plot trial, Maricopa, AZ. Sprays were made 7 days after reaching threshold (14 July) on 21 and 28 July, and 4, 18, and 26 August, except for the ‘Program’ which was skipped on the third and fifth sprays. See table 2 for treatment descriptions. Evaluations were made three times prior to and 1–3 times after each spray (DAT=days after treatment). Within an evaluation, treatments indicated with ‘•’ are significantly different from the UTC by orthogonal contrasts (•:  $P < 0.05$ ; ••:  $P < 0.01$ ; •••:  $P < 0.001$ ). Small nymph levels were lower throughout this test with few significant differences season-long. Recovery of small nymphs by sweeps may be inefficient. Regent, Vydate, and the Orthene treatments including the Program provided the most consistent control. UTC=Untreated Check. †=Program sprays and timing.

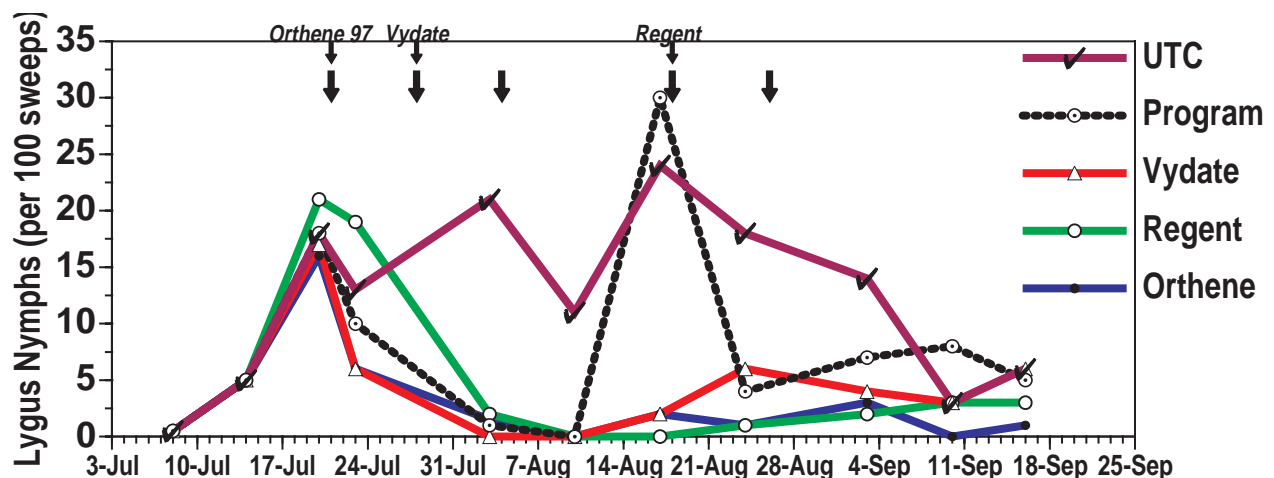


Figure 6. Number of *Lygus* nymphs per 100 sweeps ( $\pm$  SE) in response to selected insecticides in a small plot trial, Maricopa, AZ (also see fig. 3). Sprays for the 3 repeated treatments (Orthene, Regent, Vydate) are indicated with large arrows. Sprays for the ‘Program’ (Orthene fb Vydate fb Regent) are indicated with small arrows. Note the large increase in nymph levels in the Program when no sprays had been made for 21 days. Then, note the subsequent, excellent activity of the Program (Regent spray) in suppressing nymphs relative to the static levels after the fourth sprays of the repeated regimes. UTC=Untreated Check.

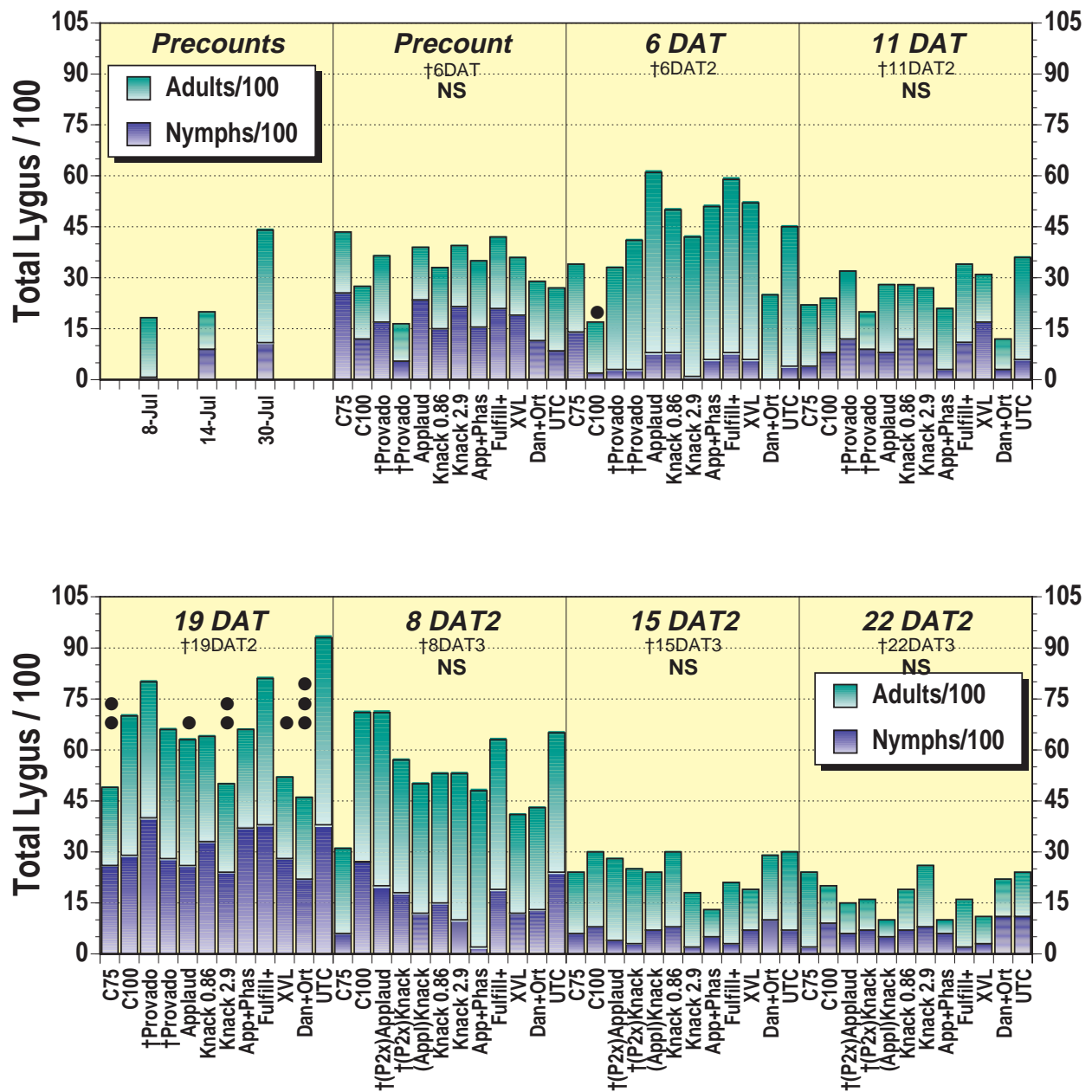


Figure 7. Total number of *Lygus* bugs per 100 sweeps in response to insecticides in a small plot trial, Maricopa, AZ. Sprays were made 16 days after reaching threshold (14 July) on 30 July (†Provado only), and 7 and 26 August, except for the Knack treatments which were sprayed only once. See table 3 for treatment descriptions. Evaluations were made three times prior to and 3 times after each spray (DAT=days after treatment). Within an evaluation, treatments indicated with ‘•’ are significantly different from the UTC by orthogonal contrasts (•:  $P < 0.05$ ; ••:  $P < 0.01$ ; •••:  $P < 0.001$ ). In general, populations were very high, and no treatment provided substantial control of total numbers. UTC=Untreated Check. †=Provado regimes’ sprays and timing.

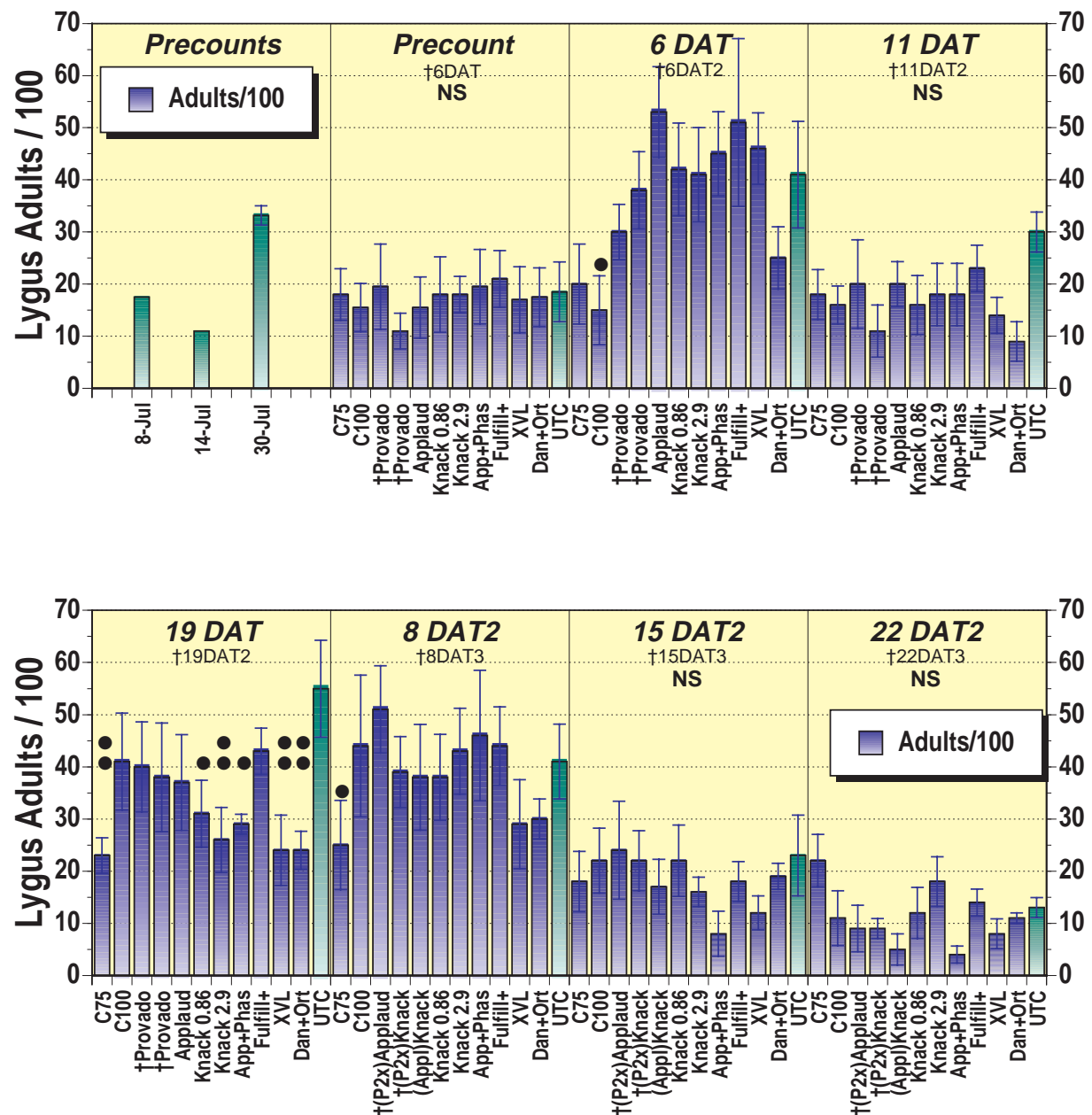


Figure 8. Number of *Lygus* adults per 100 sweeps in response to insecticides in a small plot trial, Maricopa, AZ. Sprays were made 16 days after reaching threshold (14 July) on 30 July (†Provado only), and 7 and 26 August, except for the Knack treatments which were sprayed only once. See table 3 for treatment descriptions. Evaluations were made three times prior to and 3 times after each spray (DAT=days after treatment). Within an evaluation, treatments indicated with '•' are significantly different from the UTC by orthogonal contrasts (•:  $P < 0.05$ ; ••:  $P < 0.01$ ; •••:  $P < 0.001$ ). In general, adults were not readily suppressed by these insecticides. Only Danitol + Ortherne was numerically lower than the UTC in every evaluation. UTC=Untreated Check. †=Provado regimes' sprays and timing.

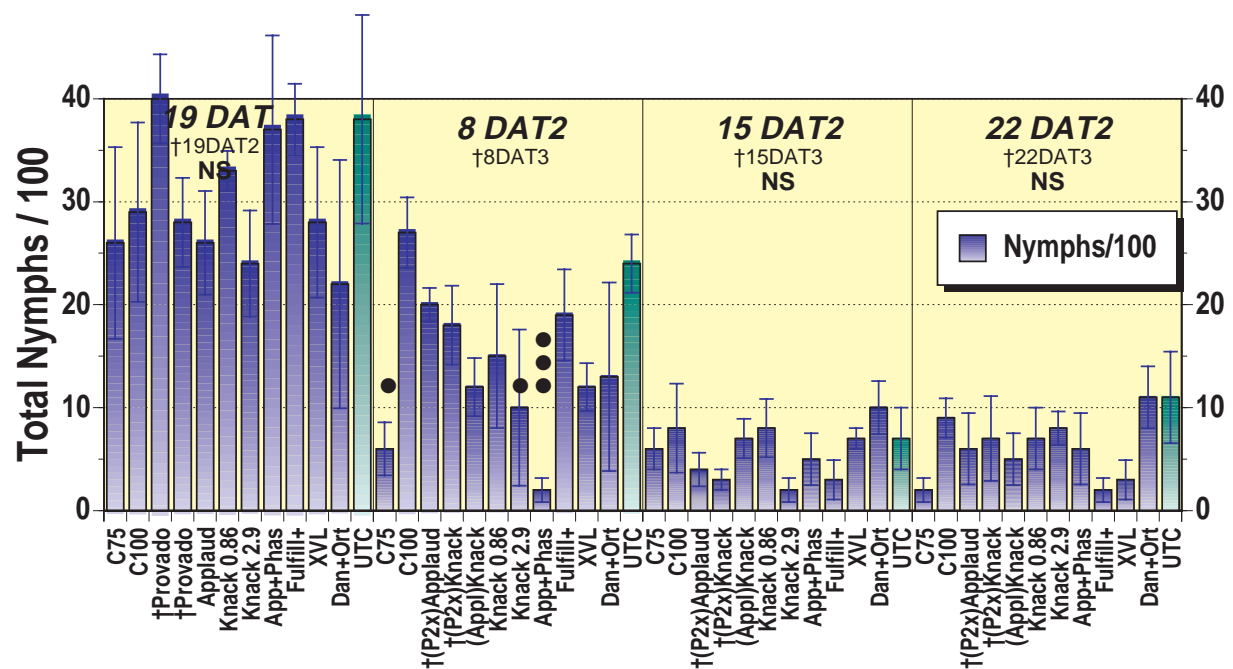


Figure 9. Total number of *Lygus* nymphs per 100 sweeps in response to insecticides in a small plot trial, Maricopa, AZ. Sprays were made 16 days after reaching threshold (14 July) on 30 July (†Provado only), and 7 and 26 August, except for the Knack treatments which were sprayed only once. See table 3 for treatment descriptions. Evaluations were made three times prior to and 3 times after each spray (DAT=days after treatment). Within an evaluation, treatments indicated with ‘\*’ are significantly different from the UTC by orthogonal contrasts (\*:  $P < 0.05$ ; \*\*:  $P < 0.01$ ; \*\*\*:  $P < 0.001$ ). There were significant treatment effects on only one date (8 DAT2), and control of nymphs in this late and limited spraying protocol was overall not very good. UTC=Untreated Check. †=Provado regimes’ sprays and timing.

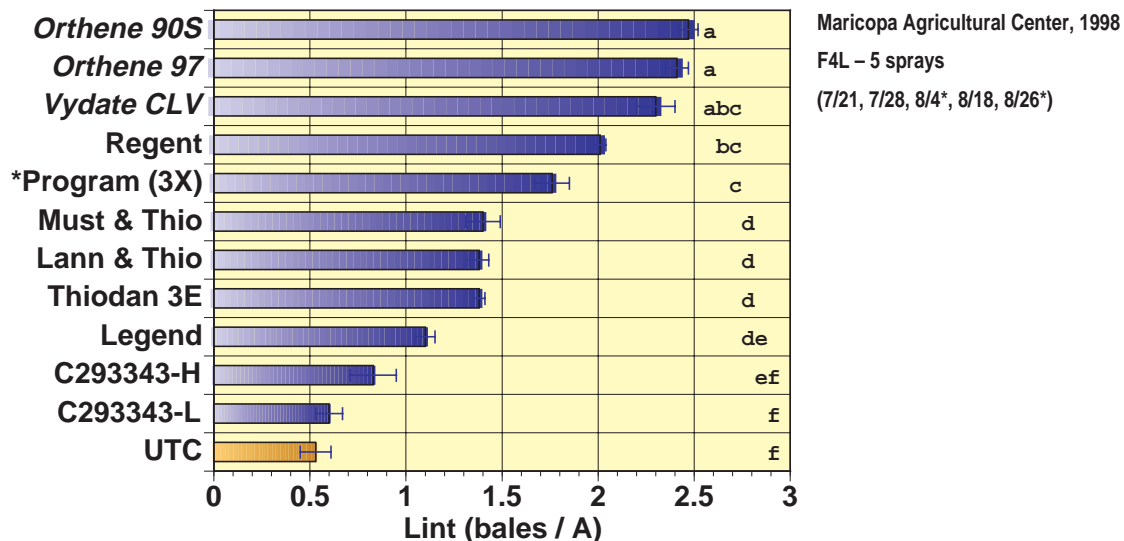


Figure 10. Lint yield (bales/A  $\pm$  SE) in response to various insecticides in a small plot trial, Maricopa, AZ. Five sprays were made against *Lygus* except for the ‘Program’ which was skipped on two dates (\*), but sprayed with a rotation of products (Orthene 97 fb Vydate, fb Regent). See table 2 for treatment descriptions. Treatments sharing the same letter are not significantly different by Tukey’s HSD ( $P > 0.05$ ). A nearly 5-fold increase in yield was measured relative to the UTC. Regent yields were compromised by defoliation by mites late in the season. UTC=Untreated Check.

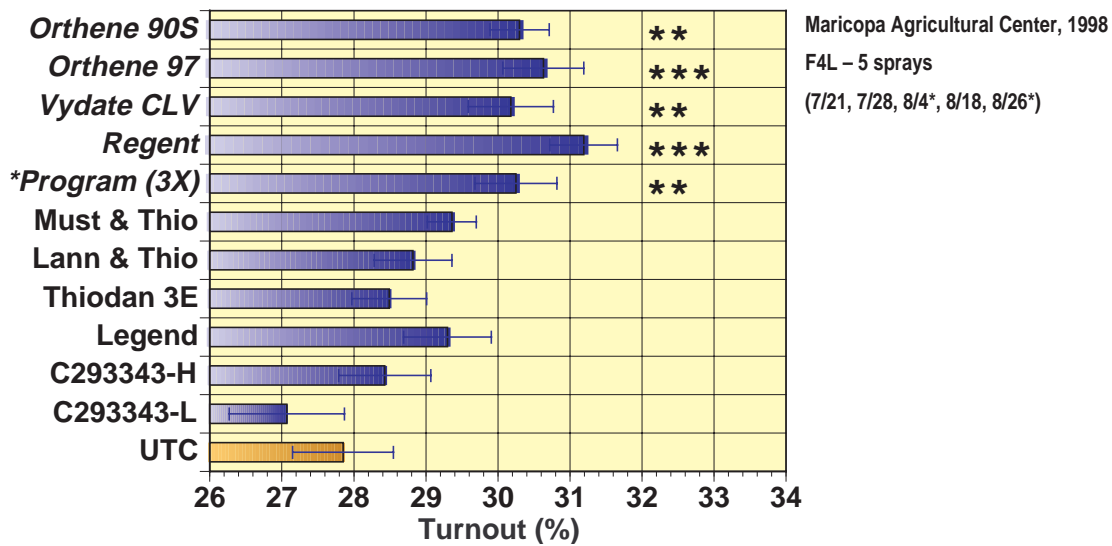


Figure 11. Lint turnout (%  $\pm$  SE) in response to various insecticides in a small plot trial, Maricopa, AZ. Five sprays were made against *Lygus* except for the 'Program' which was skipped on two dates (\*), but sprayed with a rotation of products (Orthene 97 fb Vydate, fb Regent). See table 2 for treatment descriptions. Treatments indicated (\*) are significantly different from the UTC by orthogonal contrasts (\*= $P<0.05$ ; \*\*= $P<0.01$ ; \*\*\*= $P<0.001$ ). Turnouts were highest where *Lygus* control was best. The average difference between the top five treatments and the remaining treatments was ca. 2% with Regent having the highest turnout (over 3% higher than UTC). UTC=Untreated Check.

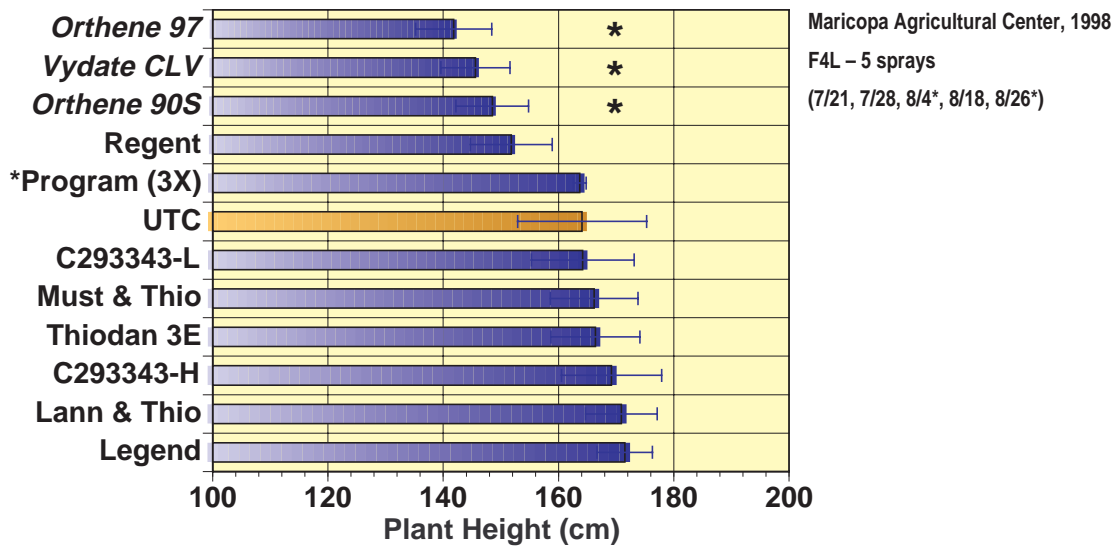


Figure 12. Final plant heights (cm  $\pm$  SE) in response to various insecticides in a small plot trial, Maricopa, AZ. Five sprays were made against *Lygus* except for the 'Program' which was skipped on two dates (\*), but sprayed with a rotation of products (Orthene 97 fb Vydate, fb Regent). See table 2 for treatment descriptions. Treatments indicated (\*) are significantly different from the UTC by orthogonal contrasts ( $P<0.10$ ). Plants were shortest where *Lygus* control was best. UTC=Untreated Check.

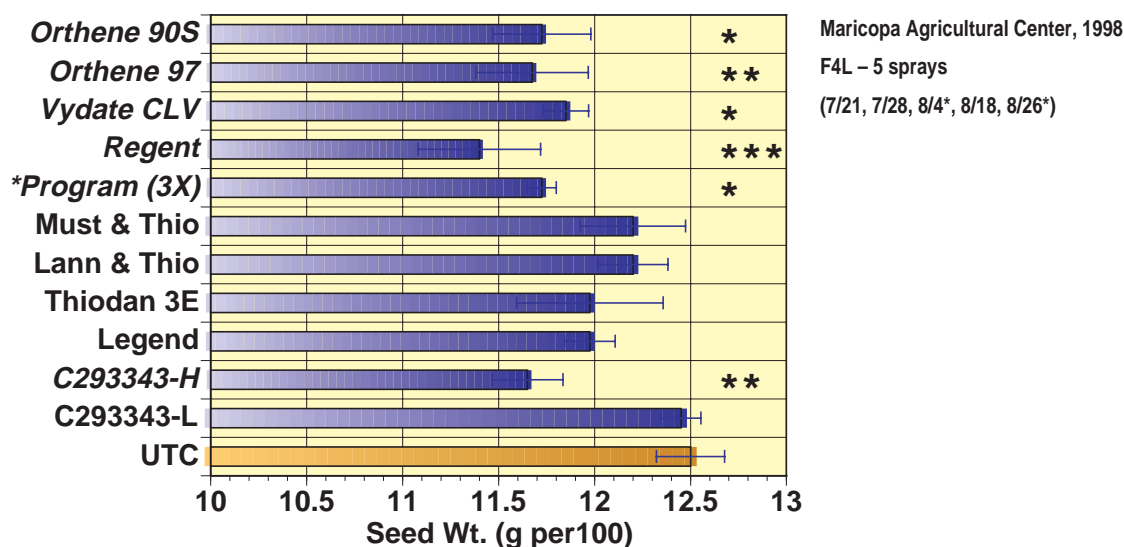


Figure 13. Seed index (g per 100 ginned seed  $\pm$  SE) in response to various insecticides in a small plot trial, Maricopa, AZ. Five sprays were made against *Lygus* except for the ‘Program’ which was skipped on two dates (\*), but sprayed with a rotation of products (Orthene 97 fb Vydate, fb Regent). See table 3 for treatment descriptions. Treatments indicated (\*) are significantly different from the UTC by orthogonal contrasts (\*= $P<0.05$ ; \*\*= $P<0.01$ ; \*\*\*= $P<0.001$ ). The top five treatments had ca. 4% lighter seeds than the remaining treatments. With more boll sinks to fill in the best performing *Lygus* treatments, carbohydrates were more evenly distributed among more, smaller-sized seeds. The Regent treatment had the smallest seed index (ca. 9% lighter than the UTC). UTC=Untreated Check.

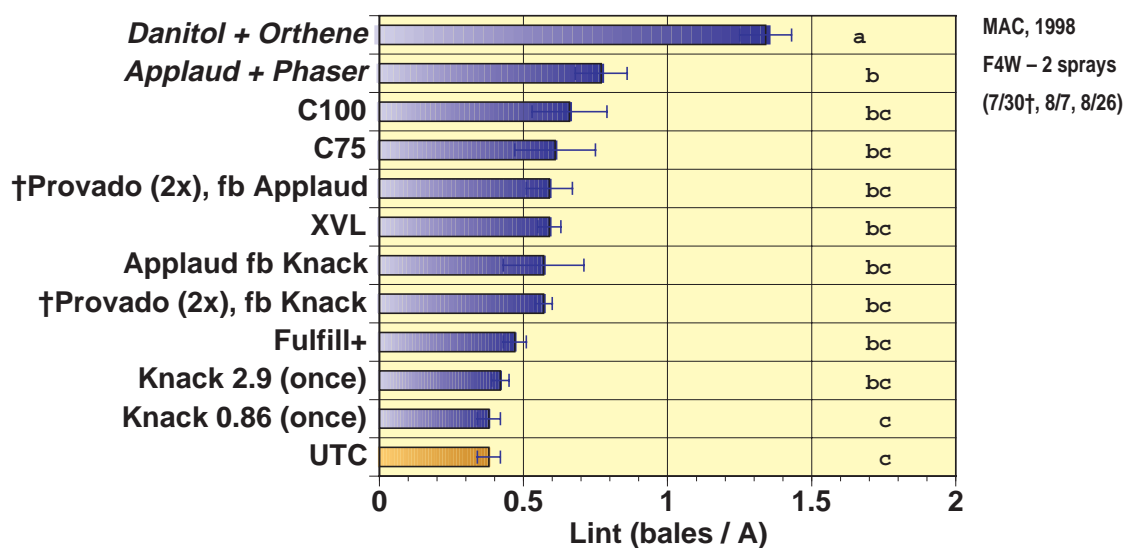


Figure 14. Lint yield (bales/A  $\pm$  SE) in response to various insecticides in a small plot trial, Maricopa, AZ. Two sprays were made against *Lygus* except for the ‘Provado’ regimes which were applied on one advanced date (†) and the ‘Knack’ regimes which were not sprayed on the last date. See table 3 for treatment descriptions. Treatments sharing the same letter are not significantly different by Tukey’s HSD ( $P>0.05$ ). An over 3-fold increase in yield was measured relative to the UTC. Only Danitol+Orthene and Applaud+Phaser had consistently significant *Lygus* efficacy. All yields were lower than the adjacent trial (see fig. 10). UTC=Untreated Check.

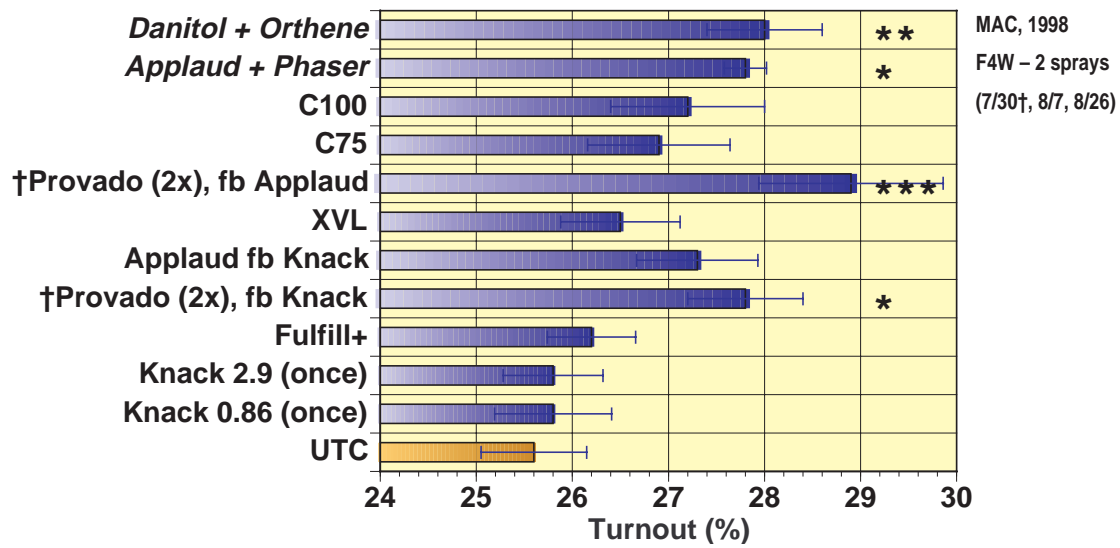


Figure 15. Lint turnout (%  $\pm$  SE) in response to various insecticides in a small plot trial, Maricopa, AZ. Two sprays were made against *Lygus* except for the 'Provado' regimes which were applied on one advanced date ('†') and the 'Knack' regimes which were not sprayed on the last date. See table 3 for treatment descriptions. Treatments indicated ('\*') are significantly different from the UTC by orthogonal contrasts (\*= $P < 0.05$ ; \*\*= $P < 0.01$ ; \*\*\*= $P < 0.001$ ). With one exception, the two best *Lygus* treatments had the highest turnouts. UTC=Untreated Check.