BEMISIA GROWTH REGULATORS: LARGE-SCALE EVALUATION

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Abstract

Two insect growth regulators (IGRs) that are selective against whiteflies (Aleyrodidae) became available for the first time in 1996 to Arizona cotton growers under emergency exemption. These IGRs were studied in a commercial-scale whitefly management trial (178 acres) in 1996. The trial was designed to evaluate provisional whitefly recommendations. Three sets of factors were tested in a 48 plot factorial design: application methods, thresholds for initiating IGR use, and insecticide regimes. Ground (broadcast at 15 gallons/acre) and aerial applications (5 gallons/acre) were roughly equivalent over a wide range of variables examined (whitefly populations, number of sprays, cost, and yield). Under the higher population densities, ground applications sometimes suppressed whiteflies to a greater extent than aerial applications. The rapid advance of the population resulted in the initial triggering of all thresholds within just five days. No consistent trend in population suppression was seen for the thresholds tested (0.5, 1.0 and 1.5 large, visible nymphs per 3.88 sq cm leaf disk located between the major and first, left lateral vein of the fifth main stem node leaf below the terminal). The control cost for the highest threshold was significantly less than for the middle threshold, but not for the lower threshold. Under emergency exemption, each IGR may be used only once per season. The sequence of use did not result in any consistent advantage in population suppression, cost, number of sprays needed, or yield. The IGR regimes were in general more efficacious, less disruptive, and less costly than the conventional insecticide regime. There were significantly fewer sprays needed by the IGR regimes compared to the conventional regime. All regimes successfully controlled whitefly populations for a 12 week period and cost significantly less than conventional programs tested in 1995 (Ellsworth *et al*. 1996a). IGRs are effective, long-lasting, and less environmentally disruptive alternatives to conventional insecticides. They reduce the risk of secondary pest outbreaks and pest resistance, and increase the opportunity of natural enemy conservation.

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:922-929 (1997)
National Cotton Council, Memphis TN

Introduction

Production of cotton in most of Arizona depends on efficient and effective control of the sweetpotato whitefly (a.k.a. the silverleaf whitefly). In a continuing effort at The University of Arizona to develop grower-relevant, research-based, pest management recommendations (Ellsworth & Diehl 1996), we have conducted a two-year study of commercial-scale whitefly management. In 1995, resistance management, efficacy, and sampling and threshold recommendations were tested in a 200 A trial using conventional chemistry (see Akey *et al*. 1996; Ellsworth *et al*. 1996a). In 1996, the insect growth regulators (IGRs), Applaud™ and Knack®, were approved for use in Arizona cotton under Section 18 emergency exemption by the EPA. Under the Section 18, cotton growers were allowed to use each product once per season only and only as part of an IPM and resistance management system. Our second year of commercial-scale testing focused on evaluation of our IPM recommendations (Ellsworth *et al.* 1995; Ellsworth & Watson 1996; Ellsworth *et al*. 1996b, c; Diehl *et al*. 1997) as changed by the availability of these IGRs and their impact on 1) the efficacy and economics of the control program, 2) the natural enemies present in cotton (see Naranjo & Hagler 1997; Naranjo *et al*. 1997), and 3) resistance to previously effective pyrethroids (Dennehy *et al*. 1997).

These variables were studied in a factorial arrangement of 48 plots, each 3–5 A in area. The factors examined included aerial and ground-applied insecticides, three different whitefly thresholds for initiating IGR use, and three insecticide regimes. Results from this study will answer grower questions about: 1) the applicability of insecticide efficacy information from a ground-based method compared with the more common aerial application method; 2) whether IGRs can perform adequately when applied by ground or air; 3) when IGRs need to be applied and at what level of whitefly nymph and adult populations; 4) if one IGR should be used first to accomplish the most efficient pest control; and 5) whether IGRs are economical alternatives to conventional chemistry.

These IGRs impact whitefly populations by interrupting key phases of the insect's growth and development. Knack interferes with egg-laying by sterilizing adult female whiteflies and preventing early egg development. It also prevents the normal emergence of the adult whitefly from the final nymphal instar (i.e., red-eyed pupa). Knack does not reduce adult numbers directly nor impact normal nymphal development. Applaud complements the modes of action of Knack by interfering with the molting process of each nymphal instar. Applaud, too, will not lower adult numbers directly. Because of the unique modes of action of these new compounds, sampling plans and thresholds had to be designed for nymphs (Naranjo & Flint 1994; Ellsworth *et al*. 1996c; Diehl *et al*. 1997) and were also tested in this large-scale experiment.

Methods

Production

Cotton (NuCOTN 33b) was planted in a skip-row configuration (6 rows planted, 2 rows skipped) on 12–14 April 1996 in four fields at The University of Arizona – Maricopa Agricultural Center's Demonstration Farm. The crop was managed according to local practices. Harvest occurred on 17–25 October and yields were estimated using two different techniques. Three, four-row subsamples per plot (2 middle rows per range) were mechanically picked by a commercial 2-row cotton picker (John Deere Model No. 9910). Seedcotton in the picker was weighed, and for the second method, this cotton along with the remainder of the plots' seedcotton was built into modules for each plot. Modules were then weighed at the gin and processed commercially. Turnouts and grades were determined commercially. Grab samples taken from the strip yield were processed and ginned by hand, and submitted for stickiness testing. Second pick and rood cotton were combined over the entire test and added to the average yields.

Design & Treatments

Each plot was about 3–5 A in area. Treatments were assigned at random and three replicates established. The treatments were: air or ground-applied whitefly insecticides; three different thresholds for initiating and re-treating with IGRs (0.5, 1.0, or 1.5 large, visible nymphs per 3.88 sq cm leaf disk from the fifth main stem node leaf below the top of the plant [see Ellsworth *et al*. 1995, 1996c]); and three insecticide regimes, 1) Applaud used first followed by Knack and conventional chemistry if needed, 2) Knack used first followed by Applaud and conventional chemistry if needed, and 3) conventional chemistry only as in 1995 (see Ellsworth *et al*. 1996a). Note that in the conventional insecticides regime (i.e., no IGRs), an adult threshold of 5 adults per leaf was used for scheduling all whitefly sprays (Ellsworth *et al*. 1995). All other pests were managed according to recommended practices over the entire test.

Two different factorial designs were analyzed by ANOVA for each week of study. In the majority of cases, all interaction terms were non-significant. In some cases, they were significant, but ecologically irrelevant because of the extremely low density at which they were detected. In very few cases, interaction terms were significant but counterintuitive. In every case where there were significant ANOVAs, the main effects of the factors analyzed were more significant than any interaction term. Replicate effects were almost always present, mainly due to an earlier and higher average whitefly density in one field. Means by week and by main effect were plotted for comparison.

Sampling, Decisions & Insect Sprays

Whiteflies were sampled according to Cooperative Extension published guidelines (Ellsworth *et al*. 1995, 1996b, 1996c). Whitefly samples were taken from each plot at least weekly and usually twice per week (N=30). Decisions were based initially on the combined average whitefly densities determined in the field from the three replicates (N=90). Field-determined densities were compared to laboratory-determined densities and new decisions made if necessary. Detached leaves were brought to the laboratory and leaf disks examined under the microscope for numbers of eggs, "small" nymphs (1st and 2nd instars) and "large" nymphs (3rd and 4th instars). Only live individuals were counted; however, dead eggs, especially those impacted by Knack, could not be reliably distinguished from live eggs. The sample unit was from Naranjo & Flint (1994) and can be approximated by a U.S. quarter, a 7/8 inch inner diameter washer, a hole-punched credit card, or No. 14 cork borer (see Diehl *et al*. 1997).

Whitefly sprays were initiated in all plots between 3 July and 8 July and continued until defoliation 12 weeks later on 22 September. A second defoliation was made on 5 October. Sprays were made usually within 24 h of the last sample. Only one other spray was required. *Lygus* bugs were sprayed on 1 August 1996 over all plots with Vydate C-LV® (0.75 lb a.i./A).

Ground applications were made by a 4-wheel drive tractor (John Deere 7400) outfitted with a broadcast 12-row boom consisting of 2 nozzles per row. Nozzles were positioned 0.5 – 1.5 ft above the canopy. All ground sprays were made at 15 GPA. Flow rates were computer-controlled (Raven® Sprayer Control). Aerial applications were made by an on-site plane (Cessna AgHusky®) and pilot with industry standard nozzles and configuration (37 CP nozzles, 0.125 orifice with 90° deflectors). All aerial sprays were made at 5 GPA over a 45 ft swath at 120 mph. Clearance above the canopy was about 8–10 ft, and target pressure (ca. 30 psi) and output were controlled by a SATLOC® automatic flow controller. Rates of all insecticides were according to current extension recommendations (Ellsworth & Watson 1996; Ellsworth *et al*. 1996b).

Results

Treatment codes, spray history and costs are listed in Table 1. The season-long weekly whitefly densities are shown in Figure 1. The general trend was a very rapid whitefly density increase starting at the end of June. The increasing slope was so severe that the lower, middle and higher thresholds all initially triggered sprays within a 5-day period. Treatments receiving conventional sprays showed rather rapid declines in adult numbers which resulted in significantly fewer eggs when compared to the IGR-initiated plots (Fig. 2). The IGR treatments had an initial increase in adult numbers after the first spray (Fig. 1: Week 1) followed by a relatively slow decline in adult numbers (Fig. 1: Weeks 2 & 3).

In contrast, large nymph numbers declined in all plots by Week 2 (Fig. 1), but then began to rebound in Week 3. This rebound in the weekly average was mostly due to the

Applaud-first treatments which re-triggered for their second spray (Fig. 3). Also in Week 3, a substantial rain occurred accompanied by high winds (> 50 mph) and dust. About half of the rain fell within a 30 minute period on 25 July. This event was coincident with a further and sharp decline in adult and nymph densities (Fig. 1). In separate experiments in the same fields, substantial nymphal removal or disappearance after this rain event was measured (Naranjo *et al*. 1997). Five other rain events were recorded (9 July, 29 August, 3 September, and 24 September) measuring 0.08–0.28 inches. None were as severe or were coincident with any significant decline in whitefly densities.

With the exception of one treatment, no sprays were made for any pests between 5 August and 4 September (Weeks 5–8; Table 1). By Weeks 8 and 9, adult and nymph numbers began to increase once again (Fig. 1). Most treatments were sprayed during Week 11 just prior to defoliation with conventional insecticides according to the adult threshold of 5 per leaf (Ellsworth *et al*. 1995). *(Note: the section 18 emergency exemption expired on 1 September making re-treatment with the second IGR impossible for the 'Knack-first', higher thresholds; Table 1).*

Application Method

The IGR application method did significantly affect weekly whitefly densities during the 12 weeks of evaluation: 3 significant weeks out of 12 weeks for the egg stage (Fig. 4), 3 weeks for small nymphs, and 4 weeks for large nymphs (Fig. 5). In only 2 of these 10 cases was aerial application more effective than ground application and this effect was detected at very low nymph densities (0.2–0.4 large nymphs per disk). The remaining significant contrasts indicated that ground applications were slightly more effective than aerial applications especially at higher average densities and during periods of most rapid population growth. The majority of the time, however, ground and aerial applications resulted in similar population levels for all life stages.

There was no consistent trend of one method being more efficient for one or the other IGR. This lack of trend extends to the separate analyses which included the conventional chemistry (Fig. 6).

IGR Threshold

The initial thresholds for IGR use were derived from past experience with IGRs on a small plot basis (Ellsworth *et al*. 1994; Ellsworth & Meade 1995; Diehl *et al*. 1997) and our extensive experience with adult thresholds (Naranjo & Flint 1994; Ellsworth 1995; Ellsworth *et al*. 1995; Naranjo *et al*. 1996). Because the 1996 recommendation was a multi-component threshold (i.e., nymphs and adult densities together) and IGRs have no lethal effect on adults, the design of this portion of the experiment was limited to an evaluation of the nymphal component of the threshold.

The IGR threshold did significantly affect weekly whitefly densities during the 12 weeks of evaluation in spite of the relatively short 5-day window in which all treatments were initiated: 3 significant weeks out of 12 weeks for small nymphs, 3 weeks for large nymphs (Fig. 7), but only during the last week for egg densities. In most cases where there were differences, the magnitudes were often very small or operating at such low whitefly densities that the effects did not appear to be of any practical significance. In the one case where the significance was large and the densities were higher (Fig. 7: Week 12), the middle threshold had fewest large nymphs (and eggs) and the higher threshold had the most. This effect was driven by two factors: 1) a late application of Applaud was made on one of the middle thresholds (Table 1: GMK) at the end of Week 8, and 2) the Knack-first treatments at the higher threshold never received their second IGR spray (with Applaud) because of the expiration of the Section 18 regulatory approval on 1 September. Thus, this effect seen just after defoliation is largely circumstantial. In general, there were no significant differences in whitefly densities for any of the IGR thresholds studied. It should be noted, however, that thresholds for re-treatment with the second IGR were made only according to nymphal densities in spite of the downward trend in adult counts during that time (e.g., Fig. 1: Weeks 3–8)

IGR Sequence & Insecticide Regime

The use sequence of the two IGRs was tested in the large factorial design. There were significant and consistent patterns of change in whitefly densities according to which IGR was currently active. Most of the Applaud-first treatments were re-sprayed with Knack between the Week 2 and Week 3 samples, so Knack was in "operation" in those treatments starting in Week 4. This reversal of compounds gives rise to a change in relative weekly whitefly densities. In Fig. 8, eggs were higher initially in the Knack/Applaud sequence (Week 2), but later the Applaud/Knack sequence had significantly more eggs (Weeks 5, 6 & 8) albeit at very low whitefly densities. This is a reflection of Knack's mode of action (i.e., eggs are sterilized) which leads to an accumulation of apparently live eggs.

This "reversal" phenomenon was continued in an examination of small nymph densities (Fig. 9). Small nymphs were higher in the Applaud/Knack sequence during Weeks 2 & 3, yet lower during Weeks 4 & 5. This again is as a result of the IGRs different modes of action. Because Knack can sterilize young developing eggs, fewer small nymphs are produced. In addition, Applaud will not kill young nymphs until the first molt, therefore, crawlers and first instars continue to be counted on Applaud-treated leaves.

The pattern can also be seen in large nymph densities (Fig. 3). Large nymph numbers tend to be lower following Knack sprays (e.g., Weeks 2 & 3 in the Knack/Applaud sequence or Weeks 4–6 in the Applaud/Knack sequence). This can be related to two factors, 1) fewer whiteflies ever reach the nymphal stage due to the sterilization properties of Knack, and 2) Knack has a longer residual than Applaud. Large nymph densities through the rest of the season were very similar between the two IGR sequences indicating that either can effectively manage whitefly populations.

The '95IRM' or conventional chemistry regime was also compared to the two different IGR sequences in a different factorial. There were significant differences in the pattern of whitefly population development among the three insecticide regimes: 4 weeks for eggs (Fig. 2), 3 weeks for small nymphs, and 2 weeks for large nymphs (Fig. 10). Most of these differences can be explained by the phenomena already described above (i.e., the differences between the two IGR modes of action). There were, however, some differences attributable to the conventional chemistry regime. Better and more rapid control of adults by the conventional adulticides was evident. This led to significantly fewer eggs in this regime during Weeks 2, 3, 5 & 6 (Fig. 2). Interestingly, small nymph numbers were still lower following Knack treatments. Large nymphs were very similar throughout the test for all three insecticide regimes (2 weeks out of 12 showed significant differences among regimes). Week 3 was the only time that the 95IRM suppressed significantly more large nymphs than the two IGR sequences (Fig. 10). By Week 4, this had changed, and the Applaud/Knack sequence had significantly fewer large nymphs. The remainder of the season showed no differences among the three insecticide regimes.

The minimum re-treatment interval observed for the three regimes were 7, 14 and 21 days for conventional insecticides (95IRM), Applaud, and Knack, respectively.

Yields & Economics

The average yield for one pick for the entire test was 2.4 bales / A. There were no significant differences among any of the factors studies (i.e., application method, IGR threshold, or IGR sequence & insecticide regime). Second pick and rood cotton brought the overall average to 2.65 bales / A.

Costs of each treatment regime are shown in Table 1. Analyses of costs according to main factors are shown in Table 2.

The IGR programs required on average 2.4 sprays (average cost = $74.81) and the conventional spray program required 4 sprays for whitefly control (average cost = $87.33). By comparison, last year's "conventional" treatment by air (A5I) required 6 sprays for a total cost of $117.27 and by ground (G5I) required 6 sprays for a total cost of $126.27 (Ellsworth *et al*. 1996a). There were no significant differences in whitefly control costs or number of sprays required between the air or ground-applied control programs (Table 2). Spraying at the higher threshold did cost significantly less than the middle, but not the lower, threshold. The conventional spray program ('95IRM') did cost more than the IGR programs though not significantly, because of the high degree of variability — note the differences between the A5I and G5I conventional programs. The '95IRM' did require significantly more sprays than the IGR programs.

Discussion

The whitefly population dynamics in late June and early July of 1996 seemed to be pointed toward some of the earliest and most severe whitefly pressure in central Arizona history. The rapid onset of threshold level populations led to the spraying of all treatments within a 5-day period. This fact probably obscured our ability to detect any large differences among thresholds. The test remains relevant; however, because this type of population progression is consistent with most previous observations in central Arizona.

The application method used in University and other scientific trials has always been a source of concern by growers. Their perception has been that "our" methods differ significantly from how growers apply insecticides. Interestingly, some growers believe that their methods, either more elaborate ground systems or aerial sprays, are more efficacious. Still others believe that the ground-based information in University studies is much better than their own standard practices. This second year study confirms that under the conditions of these studies ("average" uses of ground and air systems; 15 and 5 GPA) application methods are not a significant source of differences in the control of whitefly populations. This departs from conclusions from some other studies in other crop-insect systems; however, when differences did occur in our studies, they generally favored ground applications over aerial applications. With further investment in ground systems (higher pressures, more nozzles, or higher volumes), further gains in whitefly control may be possible. Our second year of study reported here also indicates that the new IGRs, Applaud and Knack, may be applied through ground or aerial application systems with equivalent results.

IGR thresholds were used statewide according to published provisional levels (nymphs: 0.5–1.0 large nymphs / disk plus adults: 5 / leaf). This study examined three levels of nymphs for triggering whitefly IGRs including one level over the currently recommended range (1.5 large nymphs / disk). Because of the rapid onset of whitefly populations in this study, all three thresholds triggered initially within a 5-day period. This "clustering" of treatments persisted throughout the study. Nonetheless, under these conditions of testing there were no large or consistent trends among the three thresholds for either IGR. In short, within the range tested (0.5–1.5 large nymphs / disk), both IGRs performed adequately in suppressing whiteflies. The re-treatment levels, however, were quite conservative, especially given the rather low adult densities observed at the time of re-treatment. Growers faced with similar pest densities in 1996 (i.e., "threshold" level of nymphs with few adult whiteflies present), delayed or avoided re-treatment with IGRs. This area of thresholds refinement is in need of additional study.

Growers received a Section 18 emergency exemption for one use each of two IGRs. The dilemma they faced was deciding which IGR to use first and which to hold in reserve for re-treatment after the regulated waiting period (14 days after Applaud or 21 days after Knack application). This study examined both possible deployments and found no consistent advantage of one deployment over the other. Use of Applaud first resulted in slightly fewer sprays and less money spent, though not significantly so. Knack applications whether used first or second did result in significantly fewer large nymphs. Given the large difference in cost between the two IGRs (about \$26 vs.\$40 with application costs), a grower may need to consider the severity and duration of his whitefly infestation. For instance, in areas of only sporadic infestation or with consistently late onset of whitefly threshold levels, Applaud would be a cheaper and adequate alternative to Knack. In areas of greater risk of more prolonged exposure to whiteflies (e.g., for about 30 days, but not longer), Knack might prove to be a more appropriate choice because of its longer residual. However, in areas of chronic and extended invasion by whiteflies, both IGRs might be necessary and sequence is less important. Our 1996 recommendations provided a threshold matrix to assist growers in making an IGR selection (Ellsworth *et al*. 1996c). The basic concept is when both threshold components are satisfied, infestations that are adult-skewed might be more effectively managed with Knack first (an adult and young egg sterilant). On the other hand, when infestations are nymph-skewed, whiteflies might be more effectively managed with Applaud (a nymphicide). Further testing will be necessary to support this concept.

For those growers skeptical of IGR performance relative to their conventional arsenal in 1996, this test made head-to-head comparisons of the two IGR sequences (followed by conventional insecticides if necessary) and our 1995 IRM (without IGRs). Our results clearly show that all three programs are capable of managing whiteflies season-long; however, the 95IRM may have benefited somewhat by the area-wide IGR use and suppression of whiteflies locally. In addition, the IGR program costs less to implement relative to the conventional programs (though not significantly) and took significantly fewer sprays to implement. Fewer broad-spectrum disruptions of the cotton ecosystem will likely lead to better conservation of natural enemies (Naranjo & Hagler 1997; Naranjo *et al*. 1997) and less risks of pyrethroid resistance (Dennehy *et al*. 1997). The only consistent advantage that the conventional program had over IGRs was the more immediate suppression of adult populations yielding better peace of mind to the casual observer.

Conclusions

Whitefly IGRs are powerful new tools available to Arizona cotton growers through Section 18 emergency exemption. The Section 18 was fashioned with manifold objectives: to achieve season-long management of whiteflies, to sustain or re-gain efficacy of pyrethroids and other broad spectrum insecticides through decreased reliance, to preserve the efficacy of these novel compounds by limiting their use to once per season each, and to overcome an insecticide treadmill in Arizona which has consumed cotton grower's budgets for over six years.

This test set out to provide answers to several questions of practical consequence to growers. Standard aerial and ground applications of IGRs and other chemistry are roughly equivalent in whitefly control. Ground applications appear to have potential for overcoming whitefly infestations more efficiently when the populations are high or rapidly increasing. There may be trends of enhanced conservation of natural enemies (Naranjo & Hagler 1997; Naranjo *et al*. 1997) and delayed or decreased pyrethroid resistance development for ground applications (Ellsworth *et al*. 1996a). Thresholds for initiating IGR use within the range recommended and extended in this test (0.5–1.5 large nymphs / disk) are adequate for accomplishing timely and economical whitefly control. These IGRs are slow-acting, yet forgiving, if given time to reduce the potential for generational increase. Use of IGRs leads to fewer sprays to control whiteflies. Fewer sprays means less disruption of the cotton ecosystem, greater cost savings (fewer application costs), and better chance for conservation of natural enemies and less risk of secondary pest outbreaks or pyrethroid resistance. In short IGR regimes are on average more efficacious, less disruptive and less costly. Recommendations to growers for 1997 will be revised to reflect the findings from this study.

Acknowledgments

This study is just a portion of a cooperative effort led by the scientists listed below. This portion of the trial was supported by grants from USDA CSREES Pest Management Alternatives Special Projects, National Pesticide Impact Assessment Program (Western Region), Western Region IPM Special Projects, Cotton Incorporated CORE Program, USDA-ARS, The University of Arizona Maricopa Agricultural Center, and AgrEvo, Valent and others in the agrichemical industry. Special thanks to Donna Meade, Doyle Stewart, Hal Tom, Charlie Harris, Virginia Morck, Gloria Gomez, Keegan Mahoney, Craig Gibson, John Hawkins and Judy Alexander. Project Leaders – UA-MAC: Robert Roth, Roy Rauschkolb, and Pat Murphree; CI: Robert L. Nichols; USDA-ARS WCRL: Dave Akey, Hollis Flint, James Hagler, Tom J. Henneberry, and Steve E. Naranjo; USDA-ARS SCRL: James Carlton, James Coppedge, and I.W. Kirk; UA: Tim J. Dennehy, Jon W. Diehl, Peter C. Ellsworth, and Livy Williams III.

Disclaimer

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Table 1: Experimental treatment codes[1], dates and kinds of whitefly insec-ticides applied[2], and cost of whitefly insecticide progrqam including the cost of application[3]. Rates used were according to extension recommenda-tions (Ellsworth & Watson 1996).

Code	First Spray	Second Spray	Third Spray	Fourth Spray	Fifth Spray	Cost
A5I	7-08 endosulfan + Ovasyn	7-16 Vydate + Curacron	9-08 Danitol + Orthene	—	—	57.51
AHA	7-08 Applaud	7-22 Knack	—	—	—	66.13
AMA	7-05 Applaud	7-19 Knack	9-13 Vydate + Curacron	—	—	85.90
ALA	7-05 Applaud	7-19 Knack	9-13 Vydate + Curacron	—	—	85.90
AHK	7-08 Knack	9-18 Vydate + Curacron	—	—	—	58.27
AMK	7-05 Knack	8.05 Applaud	9-16 Vydate + Curacron	—	—	85.90
ALK	7-05 Knack	8-05 Applaud	—	—	—	66.13
G5I	7-05 endosulfan + Ovasyn	7-12 Vydate + Curacron	7-19 Danitol + Orthene	9-04 Capture + endosulfan	9-19 Danitol + Vydate	117.14
GHA	7-05 Applaud	7-22 Knack	—	—	—	69.13
GMA	7-05 Applaud	7-22 Knack	—	—	—	69.13
GLA	7-03 Applaud	7-17 Knack	—	—	—	69.13
GHK	7-06 Knack	9-12 Vydate + Curacron	—	—	—	61.27
GMK	7-05 Knack	8-30 Applaud	9-17 Vydate + Curacron	—	—	90.40
GLK	7-03 Knack	7-24 Applaud	9-17 Vydate + Curacron	—	—	90.40
nG5A	7-03 Applaud	7-17 Knack	—	—	—	69.13
nG5P	7-06 Danitol + Orthene	7-16 Applaud	9-16 Vydate + Curacron	—	—	72.72

[1]3-letter treatment codes are keyed as follows: first position letters refer to the application method (A=aerial; G=ground); second position letters refer to the threshold used (L=lower, 0.5 large nymphs/disk; M-middle, 1.0 large nymphs/disk; H=higher, 1.5 large nymphs/disk; 5=5 adults/leaf); and third position letters refer to the whitefly insecticide regime used (A=Applaud-first; K-Knack-first; I=95IRM, conventional insecticides). Other miscellaneous codes pertain to treatments not reported here (n=Non-'Bt' cotton; P=pyrethroids used first).

[2]Vydate C-LV (0.75 lb a.i./A) was applied to the entire test for the control of *Lygus* bugs on 1 August.

[3]The costs of the 95IRM in 1995 (comparable to G5I and A5I) were $126.27 by ground and $117.27/A by air for 6 whitefly sprays (Ellsworth *et al*. 1996a).

Table 2. Cost ($±s.d.) And the number of sprays (±s.d.) of whitefly control programs by main factors: application method, IGR threshold, and insecti-cide regime.

		WF Control ($)	No. of Sprays
Application Method	Air	74.71 ± 12.59	2.5 ± .06
	Ground	74.91 ± 12.38	2.3 ± .05
IGR Threshold	Lower	77.89 ± 12.05	2.5 ± .06
	Middle	82.83 ± 9.38	2.8 ± .05
	Higher	*63.70 ± 4.86	2.0 ± 0.0
Insecticide Regime	Applaud 1st	74.22 ± 9.12	2.3 ± 0.5
	Knack 1st	75.40 ± 15.09	2.5 ± 0.5
	95IRM	87.33 ± 42.16	*4.0 ± 1.4

*Higher threshold cost significantly less than the middle threshold. 95IRM required significantly more sprays than the IGR-based regimes.

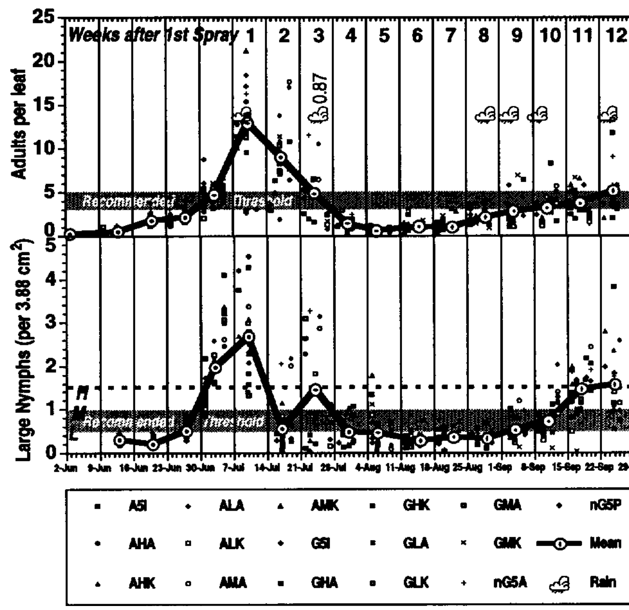

Figure 1. Season-long, weekly mean whitefly densities for adults per leaf and large nymphs per 3.88 cm^2 leaf disk (both from the fifth main stem node leaf below the terminal). Adult levels are from direct field counts (N=90). Large nymph levels are from microscope-determined counts of 3[rd] and 4[th] instars only (N=90). Means are average of the 16 treatment means. H, M, and L (higher, middle, lower) are the three candidate threshold levels of 0.5, 1.0, & 1.5 large visible nymphs per leaf disk. Gray bars represent the two components of the 1996 recommended threshold for IGR use. Symbols and codes represent the mean densities for the 16 tested treatment conditions. All sprays were initiated in Week 0 prior to Week 1 sampling. Numbers at top indicate number of weeks post-initial application. Re-treatment of most Applaud-first plots occurred in Week 2 prior to Week 3 sampling. Defoliation occurred after week 11.

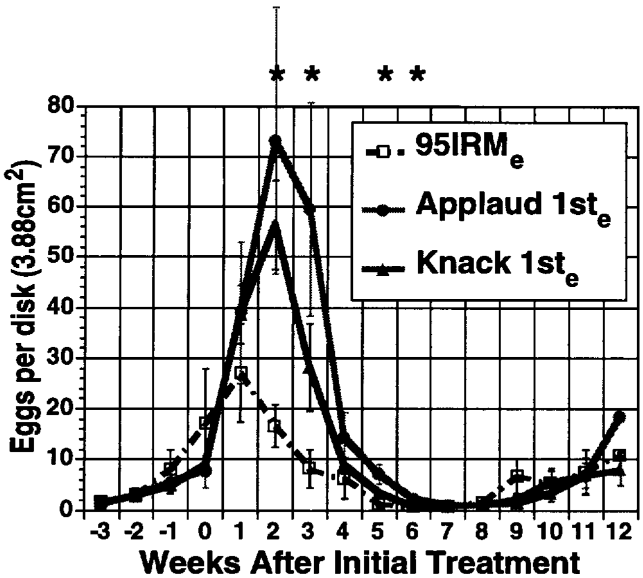

Figure 2. Eggs by insecticide regime. Whitefly egg densities by week per 3.88 cm^2 leaf disks from the fifth main stem node leaf below the terminal for the three tested insecticide regimes. 95IRM=1995 conventional chemistry recommendations; Applaud 1st=use of Applaud followed by Knack and conventional chemistry as needed; Knack 1st=use of Knack followed by Applaud and conventional chemistry as needed. '*'=weeks in which there was a significant effect of insecticide regime on egg numbers (P≤ 0.10).

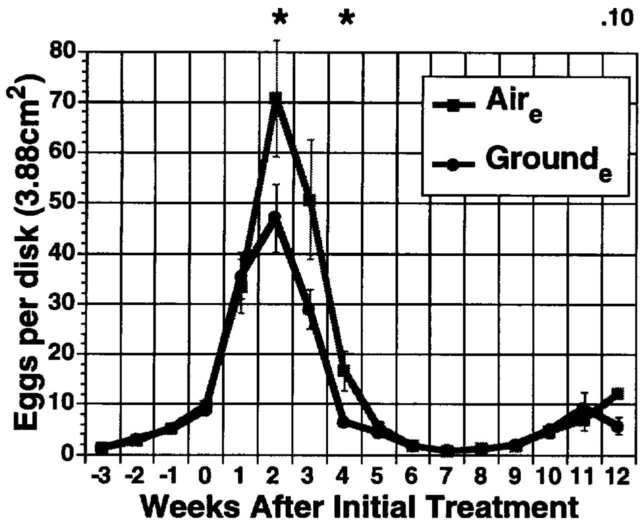

Figure 4. Egg by IGR application method. Whitefly egg densities by week per 3.88 cm^2 leaf disks from the fifth main stem node leaf below the terminal for the two tested IGR application methods. Air=aerial application of IGRs; Ground=ground application of IGRs. '*'=weeks in which there was a significant effect of insecticide regime on egg numbers (P≤0.10).

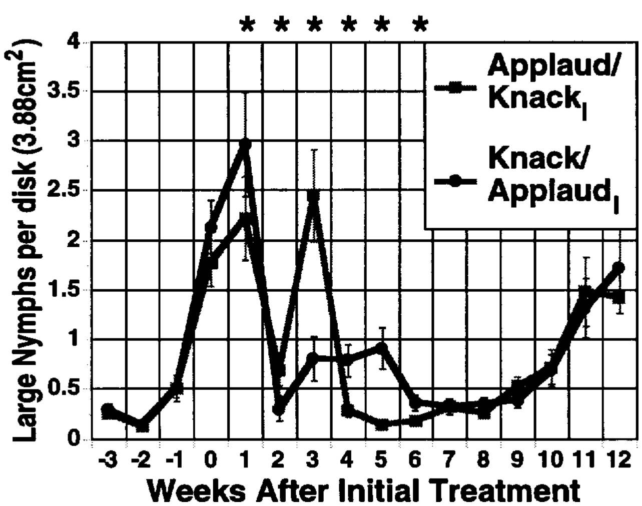

Figure 3. Large nymphs by IGR sequence. Whitefly large nymphs densities by week per 3.88 cm^2 leaf disks from the fifth main stem node leaf below the terminal for the two tested IGR sequences. Applaud/Knack=use of Applaud followed by Knack and conventional chemistry as needed; Knack/ Applaud= use of Knack followed by Applaud and conventional chemistry as needed. '*'=weeks in which there was a significant effect of insecticide regime on egg numbers (P≤0.10).

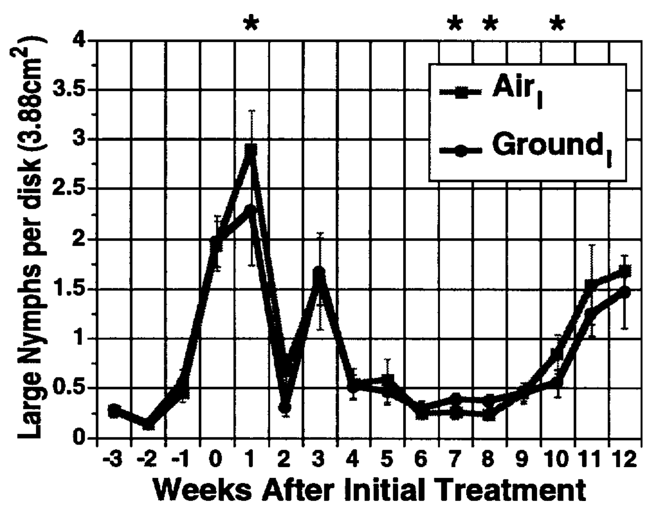

Figure 5. Large nymphs by IGR application method. Whitefly large nymphs densities by week per 3.88 cm^2 leaf disks from the fifth main stem node leaf below the terminal for the two tested IGR application methods. Air=aerial application of IGRs' Ground=ground application of IGRs. '*'=weeks in which there was a significant effect of insecticide regime on egg numbers (P≤0.10).

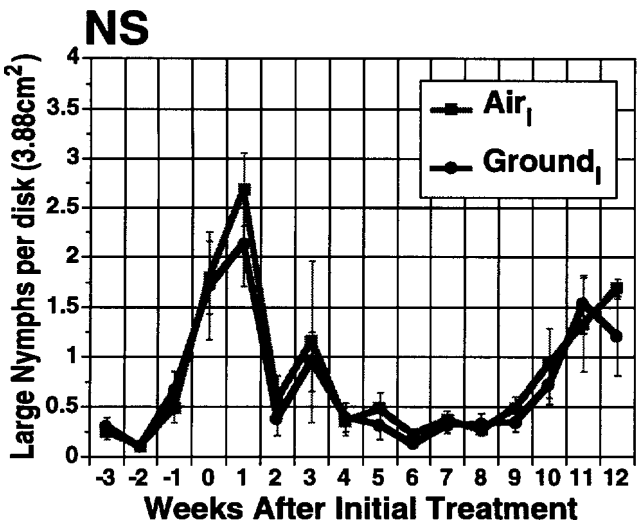

Figure 6. Large nymphs by insecticide application method. Whitefly large nymphs densities by week per 3.88 cm^2 leaf disks from the fifth main stem node leaf below the terminal for the two tested insecticide application methods. Air = aerial application of whitefly insecticides; Ground = ground application of whitefly insecticides. 'NS' = no significant difference in large nymph numbers between ground and air ($P \leq 0.10$).

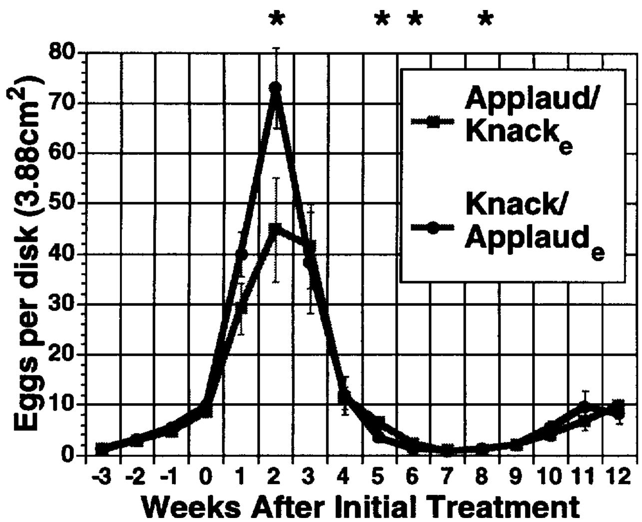

Figure 8. Eggs by IGR sequence. Whitefly egg densities by week per 3.88 cm^2 leaf disks from the fifth main stem node leaf below the terminal for the two tested IGR sequences. Applaud/Knack = use of Applaud followed by Knack and conventional chemistry as needed; Knack/Applaud=use of Knack followed by Applaud and conventional chemistry as needed. '*'=weeks in which there was a significant effect of insecticide regime on egg numbers ($P \leq 0.10$).

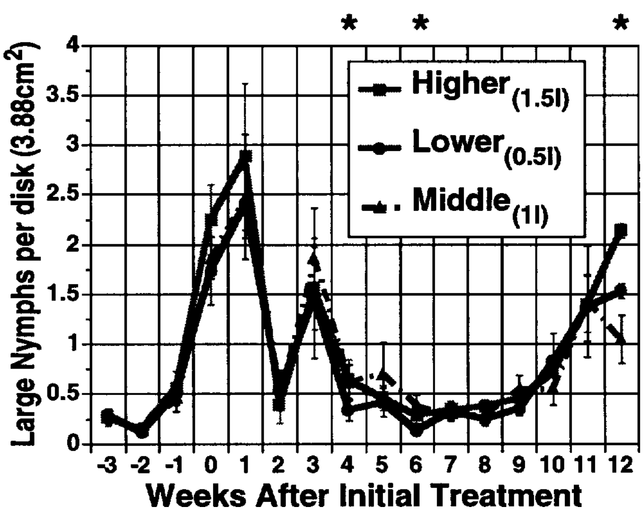

Figure 7. Large nymphs by IGR threshold. Whitefly large nymphs densities by week per 3.88 cm^2 leaf disks from the fifth main stem node leaf below the terminal for the three tested IGR thresholds. Higher = 1.5 large nymphs/disk; Middle = 1.0 large nymph/disk; Lower = 0.5 large nymph/ disk. '*'=weeks in which there was a significant effect of insecticide regime on egg numbers ($P \leq 0.10$).

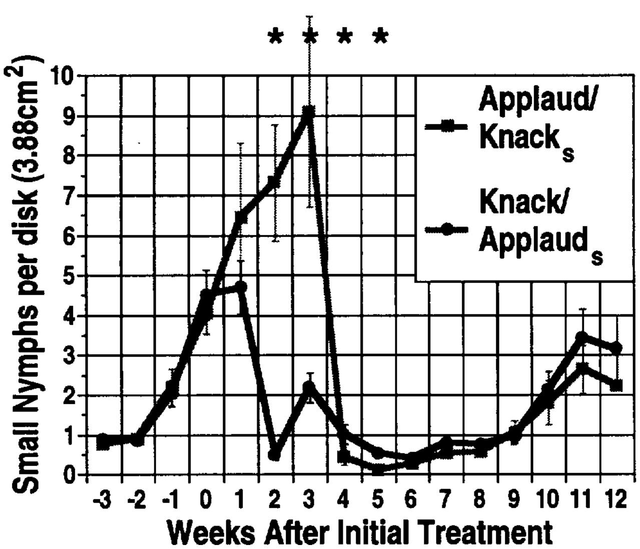

Figure 9. Small nymphs by IGR sequence. Whitefly small nymph densities by week per 3.88 cm^2 leaf disks from the fifth main stem node leaf below the terminal for the two tested IGR sequences. Applaud/Knack=use of Applaud followed by Knack and conventional chemistry as needed; Knack/ Applaud=use of Knack followed by Applaud and conventional chemistry as needed. '*'=weeks in which there was a significant effect of insecticide regime on egg numbers ($P \leq 0.10$).

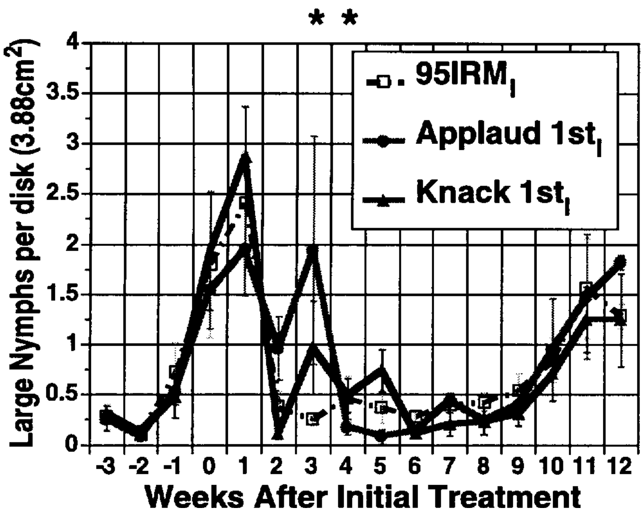

Figure 10. Large nymphs by insecticide regime. Whitefly large nymphs densities by week per 3.88 cm^2 leaf disks from the fifth main stem node leaf below the terminal for the three tested insecticide regimes. 95IRM = 1995 conventional chemistry recommendations; Applaud 1st = use of Applaud followed by Knack and conventional chemistry as needed; Knack 1st=use of Knack followed by Applaud and conventional chemistry as needed. '*'=weeks in which there was a significant effect of insecticide regime on egg numbers ($P \leq 0.10$).