

Making Late Season Decisions to Terminate Insecticide Use Against *Lygus*

Peter C. Ellsworth & Virginia Barkley
Department of Entomology & Maricopa Agricultural Center

Abstract

*The focus of our 2002 field study was to answer a fundamental question in insect control. Once spraying has begun for a particular pest, when should it stop? In this case, we are faced with the question of when to discontinue sprays for *Lygus hesperus* in cotton. Cotton is susceptible to *Lygus* any time there are productive squares on the plant. This study developed a series of worst-case scenarios in which to provide information on timing of the latest possible sprays of economic benefit. By late planting (30 May) varieties from three different maturity groups, we were able to examine *Lygus* control dynamics just prior to, at, and after cut-out — initiation of cut-out was defined as NAWF = 5. We found large differences in yield among the four *Lygus* chemical termination (LT) treatments. The earliest termination (LT1, 2 weeks prior to cut-out) suffered the largest losses to *Lygus*, ca. 20–50% of the maximum yield. Conversely, extending *Lygus* chemical control 1–3 weeks after cut-out (LT3 & LT4) provided no yield benefit whatsoever, regardless of the variety examined. Maximum yields and maximum profits were gained in the LT2, where *Lygus* controls were continued up to 1 week prior to cut-out. Given that there was only 1 week separating the LT1 and LT2 timings, it is clear that timing is absolutely critical. The timing used in this study corresponds with previously established threshold guidelines; treat when there are at least 15 total *Lygus* with at least 4 nymphs per 100 sweeps. Levels far exceeded this threshold late in the season, yet additional chemical controls after cut-out provided no additional yield or control benefits. Further, we have confirmed that nymphs are the life stage of major concern with, by far, the most capacity to reduce yields. Nymphal reductions were well-correlated with yield enhancement. The best timing (LT2) achieved ca. 93% reduction in nymphal densities during the critical 3-week period around cut-out. In contrast, adult numbers were reduced by only 16% during the same period. These results establish an upper bound for treatment of *Lygus*, no later than 1 week prior to cut-out; however, more work is necessary to identify if earlier cessation is possible under more normal planting conditions.*

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 has made major gains in the eradication, control, and management of a variety of insect pests. Still, insect pest challenges remain a significant threat to timely, economical production of cotton in Arizona. Even with the gains made in pink bollworm (*Pectinophora gossypiella*) and whitefly (*Bemisia tabaci*) management, growers still face tough decisions in pest control. With the economic climate becoming more and more difficult, producers have come to realize just how strategic each insect control input is. Many producers are analyzing their approach to insect management and questioning their previous approaches and/or the strategy implemented by their pest control advisors (PCAs). Some of these growers call the senior author or their local agents and ask hard questions about pest

This is part of the 2003 Arizona Cotton Report, The University of Arizona College of Agriculture and Life Sciences, index at <http://cals.arizona.edu/pubs/crops/az1312/>

control. While some questions are more easily answered with existing information or data, others remain unexplored in a research or carefully-monitored commercial setting. Some recent and unresolved questions include:

- 1) How late must I continue *Lygus* chemical control in order to prevent economic damage to my crop?
- 2) At what levels of *Lygus* late in the season should I be concerned about controlling?
- 3) Under what conditions might I expect significant damage to developing bolls by *Lygus*?

These top three questions in 2001 were regarding *Lygus* control, not surprising given that *Lygus* has been thrust into the No. 1 position of insect pest problems since 1997 (Ellsworth & Jones, 2001). Despite growers and PCAs reporting some of the lightest insect pressure for the last several years (esp. 1999–2002), this pest remains one of most difficult, yield-threatening, and disruptive pests to control. We have shown in previous studies a cascading set of negative impacts of *Lygus* damage that extend even beyond the major yield losses possible (Ellsworth 1998, 1999, 2000; Ellsworth & Barkley, 2001).

- 1) loss of plant height control due to reduced fruit retention and distribution. This requires further inputs of plant growth regulators like mepiquat chloride and complicates the efficient chemical control of all insects due to reduced spray penetration and coverage.
- 2) disrupted water, N, and carbohydrate source-sink relationships. This costs growers added inputs needed to achieve adequate defoliation, and interferes with picking operations.
- 3) increased trash and greater potential for excess sugars that result in stickiness. This increases harvest, storage, and ginning costs, but most of all reduces lint turnout and jeopardizes future markets.
- 4) reduced fiber quality, including high micronaire, reduced length, strength and uniformity, and color grade. Growers are all too familiar with the dynamic set of market penalties that are poised to reduce their bottom line. What they may not fully understand is that by upsetting the carbohydrate distribution within the plant due to *Lygus* damage, the remaining bolls invariably produce fibers with higher micronaire than would otherwise be realized.
- 5) disrupted natural controls that hold many secondary pests in check and help delay the need for whitefly control and extend the efficacy and bioresidual of the IGRs. Often times it is the harsh compounds required to control *Lygus* that release other pests from natural control. Some, like whiteflies, may be an inevitable threat to production, but we have shown that under some conditions *Lygus* sprays can hasten the need for chemical control of whiteflies (Ellsworth et al. 1998b; Ellsworth & Naranjo, 1999; Naranjo et al. 1998a, b; Naranjo et al. 2003b).

Industry Support for a Costly Problem?

Given these apparent and recently discovered constraints on grower profitability, one would imagine a local industry clamoring for new and continued research into more effective and more precise approaches to *Lygus* management. Modest year-to-year investments have been made in AZ; however, significant and sustained support for research on this pest is desperately needed. Nevertheless, there have been significant results from past efforts such as those detailed below.

Best Available Chemical Controls

Ellsworth (1998) quickly identified the leading candidates for *Lygus* chemical control through sponsored and unsponsored research, grower, and demonstration trials with existing and new chemistry. The results are sobering. Currently, our recommendations for *Lygus* chemical control include just two main alternatives: acephate (Orthene®) or oxamyl (Vydate®). Methamidophos (Monitor®) may be a potential alternative, but is highly toxic presenting added hazards to mixer and loaders and is rarely used today in Arizona cotton. However, the maximum rate of endosulfan is also an option that provides a different spectrum of control (i.e., including whitefly adults) that may be used by growers to control *Lygus*.

Best Available Rates and Combinations

Our program has identified the best chemical use practices for existing chemical controls (Ellsworth 1998, 1999, 2000; Ellsworth & Barkley, 2001; Ellsworth et al. 1998). We have proven over years of sponsored and unsponsored research that high rates of either Orthene or Vydate (at or near 1 lb ai / A) consistently out-perform any other single or combined materials at lower, similar, or even higher rates. We further showed that there are no additive or synergistic benefits to combining active ingredients for *Lygus* control. While mixtures may still be preferred for the control of certain pest complexes, growers should save money and improve efficacy by avoiding mixtures for the control of this pest.

New and Experimental Chemistry

Our insecticide screening program has aggressively sought out new options for *Lygus* (and other insect) control. The promising new class of chemistry, the neonicotinoids, has received much attention in the industry with control potential for many different kinds of sucking pests. Several have at one time or another been marketed for *Lygus* control or suppression (e.g., Provado® and Centric®). Our studies show convincingly that this new class of chemistry, so far, is **not** effective or commercially viable against *Lygus*. This fact alone, if heeded by growers, could save thousands of dollars by preventing 'empty' applications. Unfortunately, the list grows long of new chemistry or newly introduced products that we have screened and determined to be ineffective *Lygus* chemical control agents [pyrethroids, Provado & Leverage® (imidacloprid), Fulfill® (pymetrozine), Centric/Actara® (thiamethoxam), Intruder®/Assail® (acetamiprid), Calypso® (thiacloprid), dinotefuron, Steward® (indoxacarb), Oberon®, and many other numbered and proprietary compounds] (Ellsworth 1998, 1999, 2000, unpublished; Ellsworth et al. 1998).

One Promising New Compound

Our studies were among the first to identify fipronil as a promising new compound with *Lygus* efficacy. Small plot and large-scale, grower-cooperator, EUP studies were conducted with Regent® (fipronil) and have shown great promise for this novel compound (Ellsworth 1998, 1999; Ellsworth et al. 1999). Unfortunately, there are no current industry efforts (see below) to make this use pattern (i.e. foliar in cotton) available to cotton growers in this country, despite its current and effective use in cotton against mirid plant bugs in other countries like Mexico and Australia.

Regulatory Defense and Support of Arizona's Options in *Lygus* Control

Our efforts over the years in developing *Lygus* (and other insect) control programs have led to a very active role in defending old chemistry and supporting new chemistry within our regulatory system. The Food Quality and Protection Act requires regulatory agencies (i.e., EPA) to scrutinize the use patterns of thousands of insecticide uses. First up were the organophosphates, and chief among these was acephate (e.g., Orthene®). In 2000, we were able to successfully fend off EPA proposals that would have reduced the maximum rate of acephate by half (National Cotton Council, 2000). As a result of data available only in Arizona, we were able to document that the use pattern requiring a higher rate was not only prevalent but necessary to the economical control of *Lygus hesperus* in this state. It was clear that without the ongoing research and data collection efforts of our program, this use of Orthene would have been lost. Then, in 2002, a similar re-assessment threatened the effective rate and aerial usage of endosulfan. Once again, our research into endosulfan efficacy (as a *Lygus* and whitefly control agent) and data collection on real world use patterns (e.g., 1080 Pesticide Use Database; Cotton Insect Loss Database) have been critical to the case now pending for retaining effective uses of endosulfan (Ellsworth, 2003). The final EPA decision is pending in 2003. Finally, in 1999, we initiated and submitted a Section 18 on behalf of the cotton industry of this state requesting Regent to help mitigate the catastrophic losses to *Lygus* in the prior year (ACGA, 1999). This petition was declined by EPA; however, new ownership of this product (as of 2003) in the U.S. may provide new opportunity to establish this very effective use pattern for AZ growers.

The Role of Nymphs in Plant Damage and Yield Loss

Prior recommendations for *Lygus* control in the West were based on gross numbers of *Lygus* per 100 sweeps (Diehl et al. 1998; Ellsworth & Jones, 2001). While nymphs were always suggested as an indicator of in-field reproduction, chemical controls were often directed at and evaluated based on total numbers of *Lygus*, which are invariably adult-biased. In fact, it is not unusual to encounter populations in commercial cotton fields that are ostensibly all adults. Our work has shown definitively and repeatedly over 3 years of discontinuous study that nymphs, and, further, large nymphs are principally responsible for the damage that is preventable via chemical controls (Ellsworth 2000, 2001;

Ellsworth & Barkley, 2001). This is not to say that adults are not damaging; clearly, they are. However, the relative importance of the two life stages has likely placed too much emphasis on the easily visible adult stage, which is insensitive to our current chemical control programs, and not enough emphasis on the sampling and detection of nymphs including small nymphs, which are critical to the economic timing of insecticides.

Establishment of Research-Based Guidelines for Optimal Chemical Controls

Through a series of studies initiated in 1997 with one year support by the local cotton industry, we have firmly established science-based threshold guidelines for *Lygus* chemical control (Diehl et al. 1998; Ellsworth 1998, 2000, 2001; Ellsworth & Diehl, 1998; Ellsworth & Barkley, 2001). Cotton is a dynamic plant with tremendous capacity for growth and compensation. *Lygus* is a dynamic and mobile pest with the ability to invade fields quickly, establish, and damage plants at any time after squaring begins. Developing rational plans for sampling and decision-making for *Lygus* controls is paramount to cost-effective cotton production in AZ. Our studies established a two-component threshold known as the '15/4' level that protects yields, optimizes chemical use, and maximizes profits. This threshold requires the presence of at least 15 total *Lygus* bugs (adults and nymphs combined) with at least 4 nymphs present per 100 sweeps. These levels define the point at which chemical controls should be deployed to prevent economic damage, in general. However, given the dynamic nature of the system (plant development, insect phenology), it follows that at some point in plant development *Lygus* chemical controls are no longer necessary. While limited single year funding allows examination of only a subset of the questions related to this problem, this was the focus of our 2002 investigations.

Thus, in support of our broad 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*, we sought to address the most pressing problem reported by growers in 2001: “*How late must I continue Lygus chemical control in order to prevent economic damage to my crop?*” In addressing this question, we hoped to develop added insight into other questions with respect to *Lygus* management (e.g., see sections above). Specifically our objective is: *to identify and measure the point in crop phenology, pest dynamics, and/or damage dynamics when chemical control targeting Lygus may be discontinued.*

Our approach was to include commercial level field trials in cooperation with growers and local county agents, in potential combination with carefully controlled small plot evaluations; however, 2002 turned out to be another 'light' insect year, and efficient use of our funding limited us to on-station research where dependable levels of *Lygus* could be assured. In particular, we designed an experiment that represented the worst case scenario with respect to *Lygus* management and *Lygus* chemical termination. We wished to make the largest window of cotton production vulnerable to the largest and latest *Lygus* pressures possible. In so doing, we could establish the latest endpoint possible for *Lygus* chemical termination. Thus, with starting points in hand already, as defined by the current *Lygus* threshold guidelines (Ellsworth 2001), we could safely advise the industry as to the maximum interval during which *Lygus* chemical control has the potential for being economical. No local support is available for continuation of this or related projects in 2003.

Methods

Our approach was confined to on-station, replicated research due to the 'light' insect year most growers experienced across Arizona. The El Niño conditions this winter (2002-03) have produced some moisture that is usually indicative of a 'difficult' *Lygus* year to come due to the abundance of wild host plants.

We selected three of the most popular Bollgard® varieties in Arizona to represent the three different maturity groups: early (DP422BR), medium (DP33B), and late (DP655BR). Bollgard was used throughout to eliminate any confounding factors in pink bollworm control. Bollgard is completely effective against this pest (Ellsworth et al. 2002). The fruiting curves of these maturity groups are different in terms of initiation and duration of the primary fruiting cycle. As *Lygus* are principally square-feeders, these differences in fruiting were thought to have impact on guidelines for *Lygus* chemical termination.

There were four timings of *Lygus* chemical termination; that is the discontinuation of *Lygus* sprays. All sprays were made only when our established threshold had been exceeded. That threshold is at least 15 total *Lygus* with 4 nymphs per 100 sweeps ('15/4'). Sprays were discontinued at about two weeks before cutout (LT1), one week before cutout (LT2), one week after cutout (LT3), and three weeks after cutout (LT4) (Table 1). Varieties formed subplots within *Lygus* chemical termination whole plots replicated four times. Each subplot was 8 rows by 40 ft. The test was planted as late as commercially possible (30 May) for the area in order to place fruiting as late into the season as possible. This might simulate a double-cropped system with small grains, or a re-plant scenario, where time is not available to compensate for any in-season losses.

The IGR, Courier[®], was used over the entire test for control of whiteflies. Ovasyn[®] was added to one *Lygus* spray to enhance whitefly control. Two sprays targeting *Lygus* were made to all treatments prior to the initiation of *Lygus* chemical termination treatments (LT). Thereafter, LT1 received no more sprays, while LT2, LT3, and LT4 received one, two, and three more sprays against *Lygus*. This resulted in a contrast of two, three, four, or five total sprays against *Lygus* (Table 1). All sprays were made by a modified John Deere 6400 Hi-Cycle, delivering 20 GPA and broadcast over the top using two nozzles per row.

The entire test was defoliated with Ginstar[®] twice (8 and 23 October). The four central rows of each plot were machine harvested and weighed. Subsamples were ginned in our research gin and turnouts and other gin indices calculated. Fiber samples were submitted to the Phoenix classing office and one private lab for HVI determinations.

Lygus were sampled with a 15 in. diameter sweepnet at least weekly throughout the duration of the trial (25 sweeps per plot; 100 per treatment). All decisions to spray were based on these counts averaged over the entire *Lygus* chemical termination whole plot (i.e., 300 sweeps). *Lygus* control chemicals were rotated each time among Orthene, Vydate, and endosulfan. Nodes above white flower (NAWF) were determined from three representative plants per subplot on a periodic basis through the end of the season. For the purposes of this study, cut-out (or more correctly, the initiation of cut-out) was defined as NAWF = 5.

Results

While *Lygus* levels were generally low throughout the area, by placing our test site across a wash from a neighboring source, we were able to achieve damaging and sustained levels of *Lygus* throughout the fruiting period. This source, a poorly managed alfalfa field, matured and began to dry out around late July. By the time it was cut and watered back, a large migration of adults had already arrived in our test area. In about two weeks, egg hatch and nymphal development were sufficient to produce the four nymphs per 100 sweeps required by the '15/4' threshold; adults were already very abundant. The first *Lygus* spray was made on 5 August and the last spray in the latest treatment occurred on 20 September. Thus, *Lygus* were present and potentially damaging for a seven week period.

Plant Development (NAWF)

The first two *Lygus* sprays, in common among all treatments, were during peak fruiting. The subsequent sprays were during the latter stages of fruiting and cut-out (Fig. 1). NAWF is a convenient measure of plant developmental stage. Despite the maturity class differences of the three varieties used, there were few, if any, significant differences among these varieties during this late season interval. Had these varieties been planted during their optimal windows, we may have seen larger differences in plant development at this stage of the season. For our purposes, that of evaluating 'worst case scenarios' in *Lygus* control, the similarities in plant progression through cut-out simplified our analyses of *Lygus* chemical termination treatments. Final sprays for *Lygus* were made at two weeks prior to cut-out (NAWF = 7.2), one week prior to cut-out (NAWF = 5.9), one week after cut-out (NAWF = 4.5), and three weeks after cut-out (NAWF = 3.8). This effectively resulted in one week separation between the first two treatments (LT1 & LT2) and two weeks separation between each of the last three treatments (LT2, LT3, and LT4).

Lygus Bug Population Dynamics

Lygus sampling was conducted primarily for scheduling applications, thus biasing sampling towards the end of the effective interval of each spray. As such, these results do not provide for perfect comparative inference among *Lygus*

chemical termination treatments. Nevertheless, for the five-week period beginning at cut-out (ca. 8/29), the earliest *Lygus* chemical termination (LT1) consistently supported more *Lygus* than the other termination dates (Fig. 2). In general, each successive termination treatment had fewer *Lygus* over this five week period than the earlier termination. However, the differences were not large after the LT1, i.e., among LT2, LT3, and LT4.

What is striking about the development of *Lygus* populations in this study was the relatively large difference between LT1 and the remaining *Lygus* termination treatments (Fig. 2 & 3). In contrast, by extending the period of control with one or two more sprays than LT2, no major increases in *Lygus* control were measured. Especially when compared to the 15/4 in-season threshold, levels at this stage of the season were much higher the entire time, averaging better than three times the in-season threshold. Thus, additional sprays were routinely triggered, but the efficacy beyond LT2 was minimal. This would suggest that levels of 50 total *Lygus* with over 15 nymphs per 100 sweeps at cut-out and beyond is insufficient to cause preventable economic damage. On the other hand, levels exceeding 15/4 just one week prior to cut-out can and does cause a great deal of damage. The actual average level at the time of the LT2 spray was around 64/20 (total *Lygus* / nymphs) per 100 sweeps. Thus, this study confirms our expectation that plant growth stage and *Lygus* levels are critical to making termination decisions about *Lygus* sprays.

Yield, Ginning Properties, and Fiber Quality

The acid test for such an investigation is in yield. These varieties were grown under some of the worst conditions imaginable: a late planting faced with severe and sustained *Lygus* pressure for the majority of the primary fruiting cycle, and all with little time for compensation later in the season. Under these conditions, a two bale yield potential would have been a generous expectation, even for a better adapted variety (i.e., a short-season variety).

Seedcotton yields reached as high as just over 3000 lbs / A for LT2 of the early maturing variety. This was more than 700 lbs higher than for LT1 of the same variety. Interestingly, there was no further yield enhancement by spraying the one or two times more than the LT2. In fact, seedcotton yields declined slightly for each additional spray. This declining trend might be considered inconsequential, except for the fact that it held up over all three varieties (Fig. 4). Also, in all cases, the early maturing variety out-yielded the medium maturity variety, which, in turn, out-yielded the full season variety. Such an outcome is not unexpected when comparing these varieties in such a late production window. The 'faster' variety (DP422BR) was able to set and mature a larger proportion of its fruiting potential, while there was good in-season *Lygus* control before the termination of *Lygus* sprays.

Lint yields showed identical trends with the LT2 out-yielding all other *Lygus* chemical termination treatments (Fig. 5). Again, the full season variety suffered the most in overall yield, but also in yield reduction from LT2 to LT1. This again suggests that the early maturing variety was able to realize a larger proportion of its maximum yield before *Lygus* sprays were terminated. For each variety, LT2 was the maximum yielding treatment; and for each, LT1 was the lowest yielding treatment. For the early variety, LT1 had a 22.6% reduction in yield compared to the maximum (LT2). For the medium maturity variety, an even greater gain was attained through the additional spray from LT1 to LT2. This difference was 36.7%. However, the largest initial loss in the LT1 was for the full season variety. The LT1 was down 48.3% in yield compared to LT2.

There were no significant differences among LTs for lint turnout, lint percent, or trash (Fig. 6–8). These parameters were not adversely affected, as in past studies, because initial *Lygus* sprays (2) were made across all treatments, thus protecting the majority of the early yield component. This early control helped to maintain plant vigor to a degree where later controls, as were tested in this study, had little additional impact on plant height. Fiber qualities have yet to be analyzed.

Economics

Normally a detailed economic analysis would be required to assess the cost:benefits of additional *Lygus* controls, later and later into the season. However, the results are so definitive and so striking that a detailed analysis is unnecessary. In all cases, the maximum yield was achieved in LT2, the three spray regime that terminated *Lygus* controls on 23 August, one week prior to cut-out. Furthermore, there were no significant variety by LT interactions, which means that the same conclusions should apply to all varieties grown in a similar manner (i.e., late planting window) regardless of their maturity class. Also, in all cases, LT1 was the lowest yielding treatment. So, all that is needed is to confirm that one additional spray for *Lygus* is 'paid for' by the added yield. In this case, the gains were so large, ca.

20–50% more yield (or 690 – 1000 lbs seedcotton), and the added cost so modest (12 – 15\$ / A) that no further calculations are necessary. By the same token, it is clear that suppressing *Lygus* beyond one week prior to cut-out only costs more money with no additional yield gain. The relationship is so robust that even the most dire market conditions would result in the same conclusion (e.g., lint value of \$0.20 / lb and spray costs of \$25 / A requires only 125 lbs of lint to pay for the cost of added control).

Thus, provided that threshold levels of Lygus are present, continued spraying is warranted up to 1 week prior to cut-out, but no later, in cotton crops that are planted into a vulnerable production window (i.e., late planted).

The Role of Nymphs in Yield Loss Revisited

Our past work laid the bulk of *Lygus* ‘blame’ on the role of nymphs in causing yield loss (Ellsworth 1998, 1999, 2000, 2001; Ellsworth & Barkley, 2001; Ellsworth & Diehl, 1998). While adults are observable feeders on cotton squares and very young bolls, their role as yield-reducers has not been validated by any of our past studies. Perhaps some of this inability to detect damaging adults has been as a result of our inability to control this life stage with available chemistry. Numerous strategic and screening studies conducted in Arizona have confirmed that adults are poorly ‘controlled’ at best with our most effective chemistry. As a result, we have seldom been able to establish substantially different adult levels in experimental treatments. However, in past studies, very high yields were achieved (from 3–4 bales / A) while controlling nymphs directly, but in the presence of relatively large adult populations. Furthermore, we have presented graphical evidence via aerial photography that supports the notion that nymphs are the primary culprit in terms of cotton yield loss.

This study gives us one more opportunity to observe the relative importance of *Lygus* life stages to cotton yield loss, albeit in a window we have not examined intensively in the past. Our findings are striking and definitive. From figures 4 and 5, we know that LT2 significantly out-yielded LT1 by 20–50%. The reduction in yield, it follows, is due to the differences in *Lygus* bug numbers between these two treatments. These differences are shown in figure 3, where one can examine the critical period that differentiates the LT1 and LT2 termination timing. Note the shaded area identifying the reduction in adult (Fig. 3, left) and nymph (Fig. 3, right) numbers. Adult numbers were only reduced 12.4–21.2% (average = 16.4%) in the LT2–LT4 relative to the LT1 for the three week period between the curves. Past research has shown similarly modest reductions in adults after repeated use of *Lygus* control chemicals, and we have concluded before that this reduction in adult numbers is more a consequence of killing nymphs that would otherwise contribute to adult build-up than direct adult knockdown. In contrast, nymphal numbers during this same three week interval were dramatically reduced by 92–96% (average = 93.3%). We suggest this is the most convincing evidence to date that implicates the major role nymphs play in reducing yields of cotton. It further explains why additional gains were not made by continued spraying (LT3 and LT4). The bulk of the post-cutout control of nymphs occurred during this three week period just after the third *Lygus* spray was made (i.e., LT2). Additional sprays later did little to nothing in terms of reducing *Lygus* nymph numbers further.

Conclusions

Lygus control is and will continue to be a production imperative. On average, Arizona cotton growers spray one or two times per season to control this pest (Ellsworth & Jones, 2001). Given this consistent spray requirement, it is critical that growers have research-based guidelines for timing these sprays strategically for maximum economic return. These basic set of guidelines exist and have been proven over a wide variety of in-season environments (Diehl et al. 1998; Ellsworth & Diehl, 1998; Ellsworth 2001); treat when *Lygus* levels are at least 15 total *Lygus* with 4 nymphs per 100 sweeps. Until now, this threshold was best applied from initiation of squaring through the peak fruiting period. However, rules for discontinuing *Lygus* sprays had not been developed for this species of *Lygus* or for this part of the country. So, in those cases where growers battle chronic problems with *Lygus* requiring multiple sprays, some rational decision must be made to stop spraying at some point.

This initial study was designed to examine a set of ‘worst case scenarios’ with the goal of determining the absolute latest window in which *Lygus* control would be necessary to maximize economic returns. These conditions were met by planting varieties from three different maturity groups into a very late planting window (30 May) and exposing

them to a large and persistent population of *Lygus hesperus* for a seven week period during fruiting. This created a situation where yield potential was low to begin with, so that any gains in *Lygus* control would represent significant proportions of the overall yield. *Lygus* chemical controls were discontinued according to four different phenological timings: two weeks prior to cut-out, one week prior to cut-out, one week after cut-out, and three weeks after cut-out. For each of the three varieties tested, the result was the same. The first termination (LT1) exposed the crop to unacceptably large yield losses to *Lygus*; however, the second termination (LT2) consistently out-yielded all other treatments. Yield reductions varied from about 20 – 50% of maximum, suggesting that *Lygus* control is required as late as one week prior to cut-out under these conditions. However, more timely plantings (e.g., mid-April) may effectively set a larger proportion of their boll load prior to the arrival of *Lygus* and may have more time during which to compensate. Thus, further work should be conducted to address the array of possible outcomes for different planting windows and *Lygus* population dynamics. This current work has also shown no significant interaction between variety and *Lygus* termination timing. Thus, future work may be simplified by examining only a small number of varieties to develop a generalized damage function for *Lygus*.

With this very modest investment in our research, we have been able to define the latest window in which *Lygus* control is still profitable, i.e., one week prior to cut-out. Thus, growers considering controlling *Lygus* later than this can save money by terminating sprays earlier. On the other hand, growers who give up the battle too soon, especially for late planted cotton, are likely giving up significant yields to this damaging pest. These studies further support the findings of past work that adults are playing a relative minor role in recoverable yield loss, and that small bolls are likely not major food sources for *Lygus*. If the opposite were true, we would have likely seen continued, major enhancements of yield with later *Lygus* controls. Thus, strategies should focus on avoiding *Lygus* altogether through careful crop placement and conservation of early season natural enemies by using selective technologies like Bt cotton and IGRs; detecting and sampling *Lygus* all season long through comprehensive plans of at least 100 sweeps per management unit; treating once there are at least 15 total *Lygus* and, very importantly, at least 4 nymphs per 100 sweeps; and finally, discontinuing sprays for *Lygus* no later than one week before cut-out (cut-out = 5 NAWF). Earlier termination may be possible; however, further research into this question would be necessary to guide growers in the future.

So our recommendation is to continue tracking both adult numbers and nymph numbers. The former indicates the reproductive potential of the population in the field. The latter is critical to understanding when the economic conditions favor a decision to treat. Thus, '15/4' (i.e., 15 total *Lygus* with 4 nymphs per 100 sweeps) remains our in-season guideline for *Lygus* chemical control. However, now we know that controls should cease no later than the one week prior to cut-out, because control after this point is unwarranted no matter the *Lygus* levels. Cessation of sprays might occur sooner in situations where more of the yield component is realized earlier in the fruiting curve, usually as a result of a more optimal planting window. However, more research will be necessary to guide grower's *Lygus* management efforts under a dynamic set of conditions in the future.

Acknowledgments

The authors would like to thank the staff of the Maricopa Agricultural Center for providing 'safe haven' for our *Lygus* trials; something few are willing to do. We also would like to thank our dedicated staff of bug samplers (Krystal Barkley, Stella Benitez, Rhonda Roth, Enrique Yescas, Gilberto Castro, Francisco Bojorquez, Chris Holt, Israel Peña, Jennifer Snyder, Heidi Heun, Brian Mikel) and the Arizona Cotton Growers Association and Cotton Incorporated for support of this effort. We would also like to recognize the in-kind provision of *Lygus* (and other insect) control chemicals from our various industry partners (Nichino, DuPont, and Valent).

References

- Arizona Cotton Growers Association [P.C. Ellsworth, ed.]. 1999. Arizona Section 18 Request for Regent® against *Lygus* in Cotton. 26 pp. <http://ag.arizona.edu/cotton/regent18.pdf> (Principal author)
- Diehl, J.W., P.C. Ellsworth & L. Moore. 1998 (7/98). *Lygus* in Cotton No. 1: Identification, Biology & Management. The University of Arizona, Cooperative Extension, 2 pp. URL: <http://ag.arizona.edu/crops/cotton/insects/lygus/lygus1.pdf>
- Ellsworth, P.C. 1998. Integrated *Lygus* management in Arizona. In J.C. Silvertooth [ed.], Cotton, A College of Agriculture

- Report. Series P-112. University of Arizona, College of Agriculture, Tucson, AZ. pp. 403–407.
- Ellsworth, P.C. 1999. Evaluation of chemical controls of *Lygus hesperus* in Arizona. In J.C. Silvertooth [ed.], Cotton, A College of Agriculture Report. Series P-116. University of Arizona, College of Agriculture, Tucson, AZ. pp. 428–447.
- Ellsworth, P.C. 2000. *Lygus* control decision aids for Arizona cotton. In J.C. Silvertooth [ed.], Cotton, A College of Agriculture Report. Series P-121. Publ. No. AZ1170. University of Arizona, College of Agriculture, Tucson, AZ. pp. 269–280. <http://ag.arizona.edu/crops/cotton/insects/lygus/lyg00cr.pdf>
- Ellsworth, P.C. 2001. *Lygus* in Cotton No. 3: Implementing Action Thresholds. The University of Arizona, Cooperative Extension, 2pp. URL: <http://ag.arizona.edu/crops/cotton/insects/lygus/lygus3.pdf> (750)
- Ellsworth, P.C. (with supporting data from E. Shanley & P. Baker). 2003. Endosulfan re-registration eligibility decision, Arizona pesticide usage data. EPA Public Comment, Docket ID No. OPP-2002-0262. 15 pp.
- Ellsworth, P.C. & J.S. Jones. 2001. Cotton IPM in Arizona: A decade of research, implementation & education. In J.C. Silvertooth [ed.], Cotton, A College of Agriculture and Life Sciences Report. Publ. No. AZ1224. University of Arizona, College of Agriculture and Life Sciences, Tucson, AZ. pp. 199–215. <http://ag.arizona.edu/pubs/crops/az1224/>
- Ellsworth, P.C. & J.W. Diehl. 1998 (7/98). *Lygus* in Cotton No. 2: An Integrated Management Plan for Arizona. The University of Arizona, Cooperative Extension, 2pp. URL: <http://ag.arizona.edu/crops/cotton/insects/lygus/lygus2.pdf>
- Ellsworth, P.C. & S.E. Naranjo. 1999. Whitefly management with insect growth regulators and the influence of *Lygus* controls. In J.C. Silvertooth [ed.], Cotton, A College of Agriculture Report. Series P-116. University of Arizona, College of Agriculture, Tucson, AZ. pp. 339–354.
- Ellsworth, P.C. & V. Barkley. 2001. Cost-effective *Lygus* management in Arizona cotton. In J.C. Silvertooth [ed.], Cotton, A College of Agriculture and Life Sciences Report. Publ. No. AZ1224. University of Arizona, College of Agriculture and Life Sciences, Tucson, AZ. pp. 299–307. <http://ag.arizona.edu/pubs/crops/az1224/az12247j.pdf>
- Ellsworth, P.C., R. Gibson, D. Howell, S. Husman, S. Stedman & B. Tickes. 1998a. *Lygus* chemical control: Are combination sprays worth it? In J.C. Silvertooth [ed.], Cotton, A College of Agriculture Report. Series P-112. University of Arizona, College of Agriculture, Tucson, AZ. pp. 408–421.
- Ellsworth, P.C., S.E. Naranjo, S.J. Castle, J. Hagler & T.J. Henneberry. 1998b. Whitefly management in Arizona: Looking at whole systems. In J.C. Silvertooth [ed.], Cotton, A College of Agriculture Report. Series P-112. University of Arizona, College of Agriculture, Tucson, AZ. pp. 311–318.
- Ellsworth, P.C., B. Deeter & M. Whitlow. 1999. EUP evaluation of a novel insecticide for *Lygus* control. In J.C. Silvertooth [ed.], Cotton, A College of Agriculture Report. Series P-116. University of Arizona, College of Agriculture, Tucson, AZ. pp. 459–467.
- Ellsworth, P.C., H. Moser, T. Henneberry, G. Majeau & J. Subramani. 2002. Transgenic comparisons of pink bollworm efficacy and response to heat stress. In J.C. Silvertooth [ed.], Cotton, A College of Agriculture and Life Sciences Report. Publ. No. AZ1283. University of Arizona, College of Agriculture and Life Sciences, Tucson, AZ. pp. 147–157. <http://ag.arizona.edu/pubs/crops/az1283/>
- Naranjo, S.E., J.R. Hagler & P.C. Ellsworth. 1998a. Whitefly management in Arizona: Conservation of natural enemies relative to insecticide regime. In J.C. Silvertooth [ed.], Cotton, A College of Agriculture Report. Series P-112. University of Arizona, College of Agriculture, Tucson, AZ. pp. 319–323.
- Naranjo, S.E., P.C. Ellsworth & J.W. Diehl. 1998b. Whitefly management in Arizona: Contribution of natural enemies to whitefly mortality. In J.C. Silvertooth [ed.], Cotton, A College of Agriculture Report. Series P-112. University of Arizona, College of Agriculture, Tucson, AZ. pp. 324–329.
- Naranjo, S.E. J.R. Hagler & P.C. Ellsworth. 2003a. Improved conservation of natural enemies with selective management systems for *Bemisia tabaci* in cotton. *Biocontrol Science & Technology*, in press.
- Naranjo, S.E., P.C. Ellsworth & J. Hagler. 2003b. Conservation of natural enemies in cotton: Role of insect growth regulators for management of *Bemisia tabaci*. *Biological Control*, in submission.
- National Cotton Council. [K. Menchey & P.C. Ellsworth]. 2000. Benefits of acephate for *Lygus* control in Arizona cotton production. Report to US-EPA. 12 pp.

Table 1. Insect spray records for the four *Lygus* chemical termination treatments (LT1–LT4) under study. All three varieties were sprayed at the same time for each LT treatment. Two sprays were made in-season to all four LT treatments. Thereafter, *Lygus* control was suspended at varying times according to the LT treatment. The result was two, three, four, or five *Lygus* sprays for LT1, LT2, LT3, and LT4, respectively.

Lygus Chemical Termination (LT)				
<i>02F4LT, B21-23</i>	LT1	LT2	LT3	LT4
5-Aug	<i>Courier</i> (0.35) + <i>Vydate</i> (1.0)			
16-Aug	Endosulfan (1.5) + <i>Ovasyn</i> (0.25)			
23-Aug		<i>Orthene</i> (1.0)	<i>Orthene</i> (1.0)	<i>Orthene</i> (1.0)
6-Sep			<i>Vydate</i> (1.0)	<i>Vydate</i> (1.0)
20-Sep				Endosulfan (1.5)
Lygus Sprays	2	3	4	5

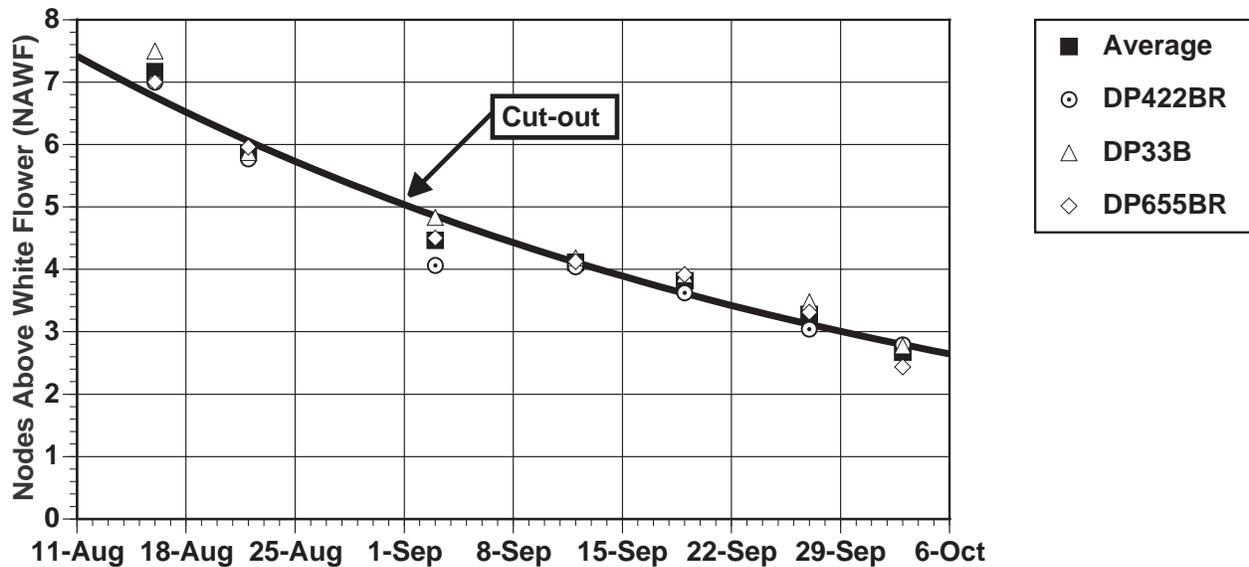


Figure 1. Progression of crop development for three different maturity classes as indicated by the nodes above the uppermost first position white flower (NAWF). Initiation of cut-out is defined as NAWF = 5, which occurred on 31 August, 2002, in this study. There were no consistently significant differences in NAWF among varieties or *Lygus* chemical termination treatments. The fitted regression is to the average response ($R^2 = 0.97$).

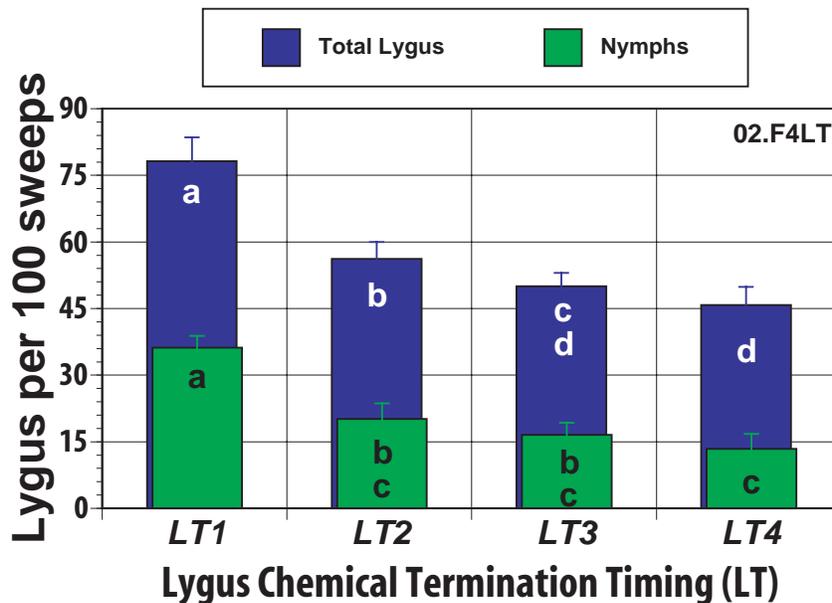


Figure 2. Average numbers of *Lygus* per 100 sweeps for the five-week period from cut-out to the end of the sampling period (8/29, 9/3, 9/11, 9/19 & 9/25). There were no significant differences among varieties and no interactions, so the data were pooled by *Lygus* chemical termination treatment. LT1 had significantly more *Lygus* in total and more nymphs than the remaining three LT treatments. Differences among the remaining three LT treatments were minor and not significant for nymphs. The in-season threshold for *Lygus* control is 15 total *Lygus* with at least 4 nymphs per 100 sweeps. Levels during cut-out were far in excess of this threshold for all treatments. Colored bars sharing the same letter are not significantly different (orthogonal contrasts; $P = 0.05$).

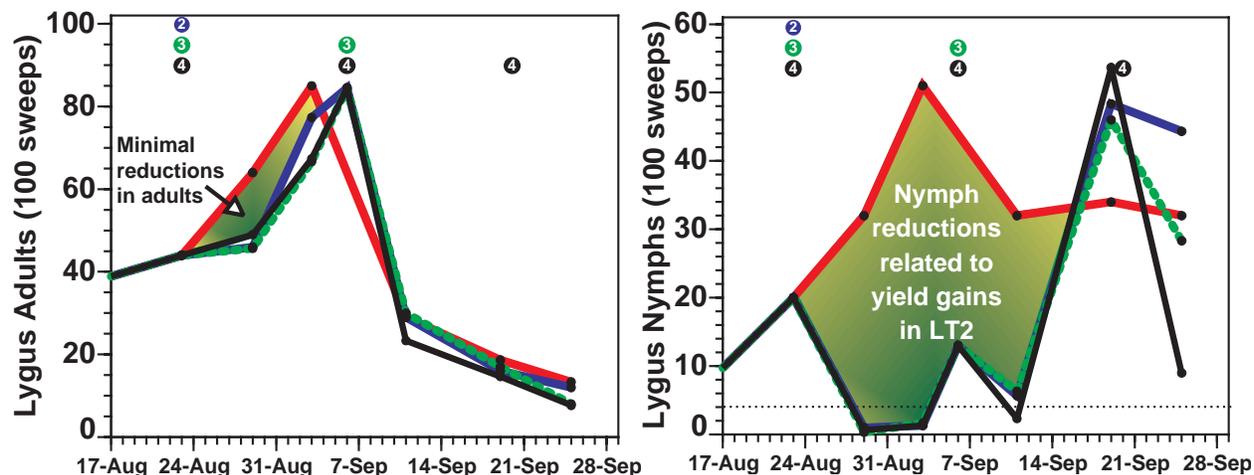


Figure 3. Average *Lygus* adults (left) and nymphs (right) per 100 sweeps during the end of the season for each *Lygus* chemical termination treatment (LT1–LT4). Numbered bubbles and matching colored lines correspond to the LT treatment number and color, and denote the timing of each LT spray. Dotted line corresponds to the nymphal component of the in-season *Lygus* threshold that was used for triggering treatments in this experiment. The shaded area demarcates the reduction in *Lygus* populations accomplished by the LT2 treatment compared to the LT1 treatment (red line). Reductions in adult numbers were minimal (3-week average of 16.4%) and not correlated with yield gains. However, reductions in the numbers of nymphs were significant (3-week average of 93.3%) and well-correlated with yield gains made by LT2 over LT1. This suggests that nymphs are principally responsible for the preventable yield losses incurred in LT1, and explains why LT3 and LT4 (i.e., continued spraying) did not produce any additional yield advantage.

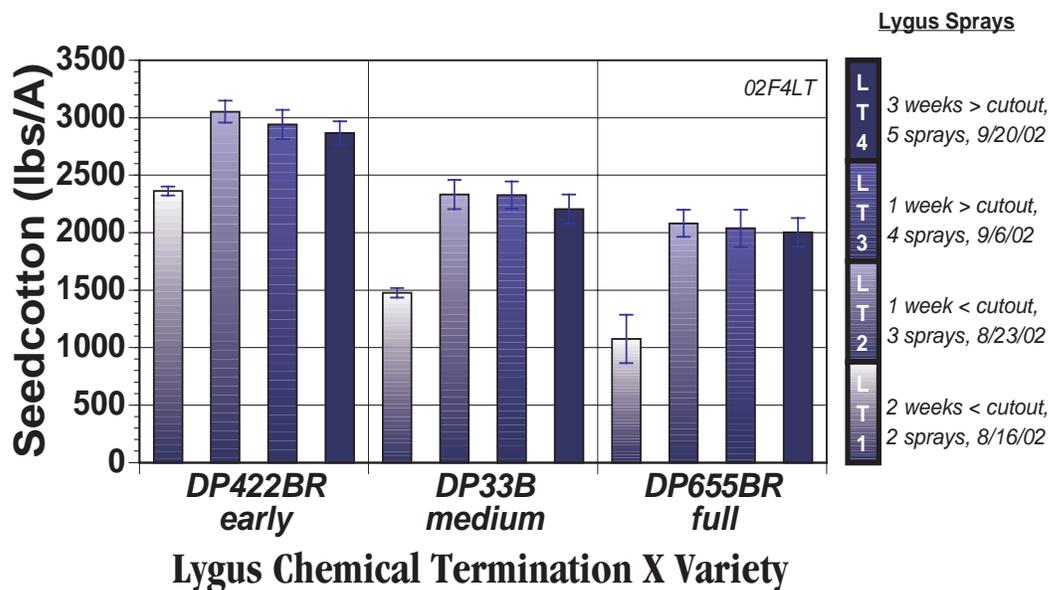


Figure 4. Seedcotton yields (in lbs / A) from three different varieties, representing three maturity groups, and four *Lygus* chemical termination regimes (LT1–LT4). The early maturing variety significantly out-yielded the medium maturity variety, which out-yielded the full season variety. Within each variety, the LT1 timing resulted in a significantly reduced yield compared to each of the alternative timings (LT2–LT4). No additional yield was produced as a result of additional sprays beyond the LT2.

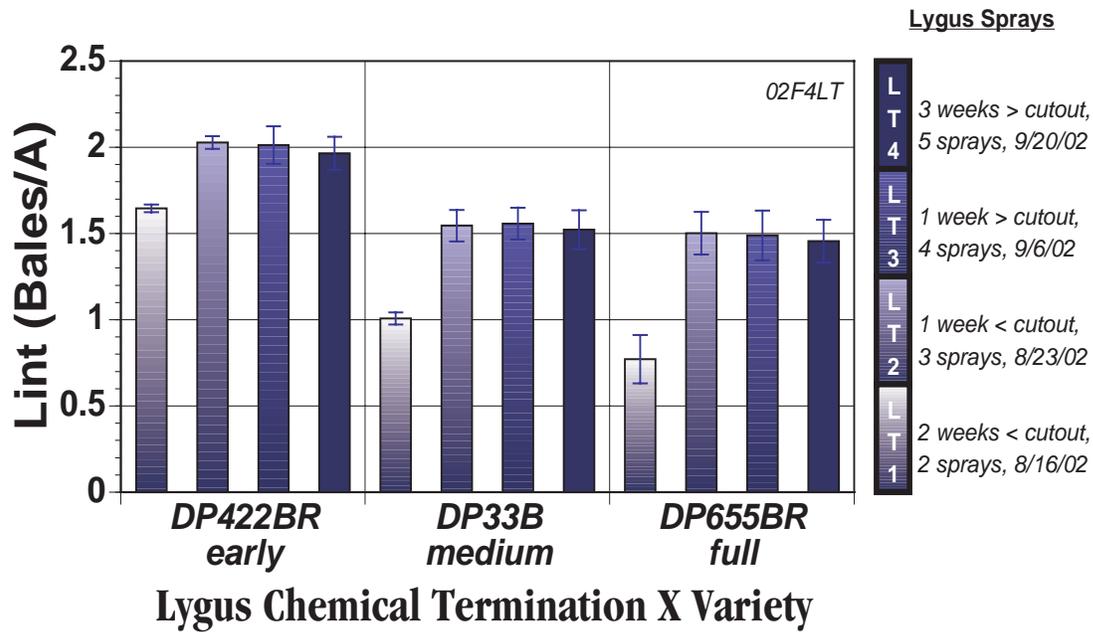


Figure 5. Lint yields (in 480 lb bales / A) from three different varieties, representing three maturity groups, and four *Lygus* chemical termination regimes (LT1–LT4). The early maturing variety significantly out-yielded the medium maturity variety, which out-yielded the full season variety. Within each variety, the LT1 timing resulted in a significantly reduced yield compared to each of the alternative timings (LT2–LT4). No additional yield was produced as a result of additional sprays (LT3 or LT4) beyond the LT2.

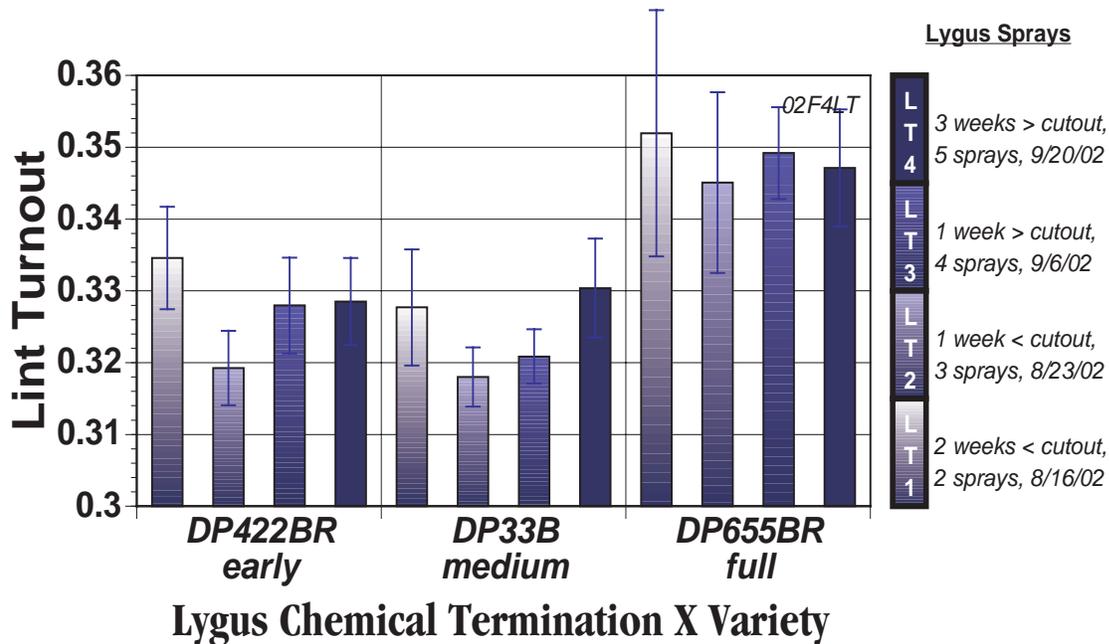


Figure 6. Gin turnouts of lint from three different varieties, representing three maturity groups, and four *Lygus* chemical termination regimes (LT1–LT4). The full season variety had significantly higher lint turnouts than the other two varieties. Within each variety, there were no significant differences among *Lygus* chemical termination timings (LTs).

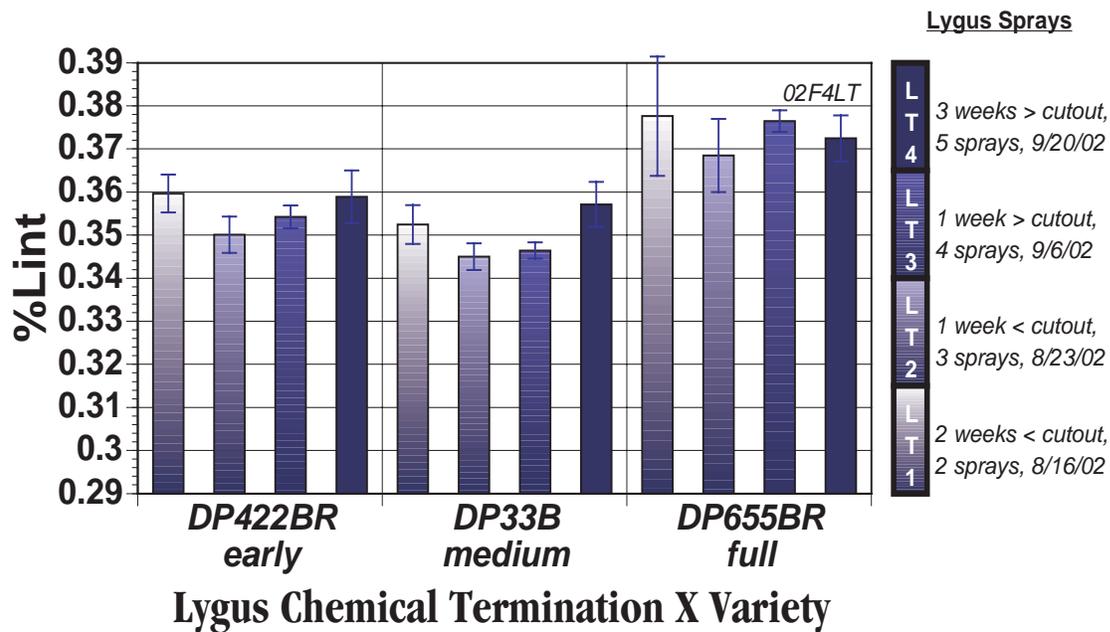


Figure 7. Percent lint from three different varieties, representing three maturity groups, and four *Lygus* chemical termination regimes (LT1–LT4). The full season variety had significantly higher %Lint than the other two varieties. Within each variety, there were no significant differences among *Lygus* chemical termination timings (LTs).

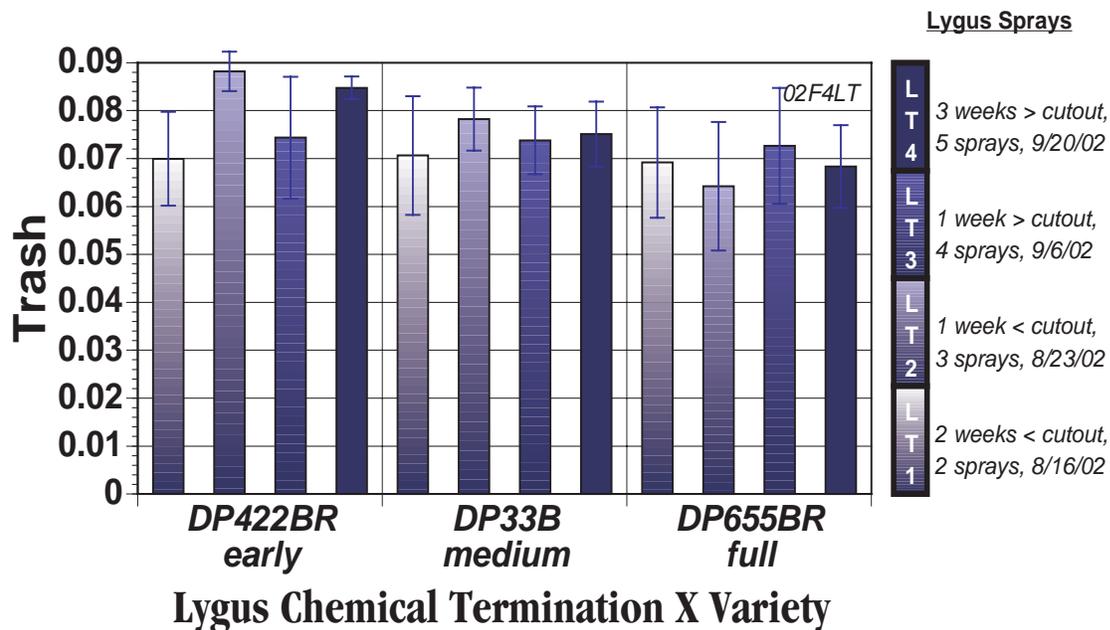


Figure 8. Proportion of trash from ginning the seedcotton of three different varieties, representing three maturity groups, and four *Lygus* chemical termination regimes (LT1–LT4). There were no significant differences among varieties or *Lygus* chemical termination timings (LTs).