COST-EFFECTIVE *LYGUS* MANAGEMENT IN ARIZONA COTTON

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Abstract

Timing sprays for maximum return on investment requires sampling and counting both *Lygus* adults and nymphs in a minimum of 100 sweeps. Once at least 15 total *Lygus* **and** 4 nymphs per 100 sweeps are detected, sprays for *Lygus* should be made. This '15/4' regime should protect yields, moderate spray frequency and costs, and maximize profit. Economic thresholds are impacted by the prevailing economic conditions such as lint value and costs of control; however in this case, the relationship that maximizes returns was not changed when varying these parameters well beyond market standards.

A key finding of these studies is that aside from profits, yields plateau prior to the more aggressive treatment regimes. This phenomenon, where more protective approaches result in yield reductions, occurred in all three years of study (1997, 1999, 2000). This signals the importance of optimizing inputs so that sprays are made only when indicated by sampling and once the 15/4 level is reached, but no sooner. More aggressive approaches by definition cost more money to maintain, but also have some probability of lowering yields while risking secondary pest outbreaks. The specific mechanism for this yield decline is unknown at this time. At the other end of the spectrum, delaying action beyond the 15/8 action threshold risks economic yield loss and reductions in quality, especially color grade and micronaire.

While this work definitively establishes the relative importance of *Lygus* nymphs to yield loss and to the need for action, the conditions under which these tests were carried out are limited to in-season infestations of *Lygus*. Further work is necessary to better quantify change in the action levels according to plant phenology and other plant-based factors (e.g., plant population, fruit retention, plant-water status, etc.). Early season infestations may respond differently to the action levels proposed, and it is expected that later season populations of *Lygus* pose far less damage potential when square populations and retention are very low.

Introduction

Lygus hesperus Knight is a perennial pest of Arizona cotton. Growers and practitioners have dealt with its presence for decades. This familiarity has produced some level of confidence within the industry that they understand the problem, and the solutions and manner in which to implement them. University of Arizona recommendations have typically been to sample using a sweepnet and treat when there are 15–20 total *Lygus* / 100 sweeps. A suggestion has been made that nymphs should be present, indicative of a resident and reproducing population, and that some level of square loss should be measured (Moore, 1972). Most of these recommendations have stood unchanged for over 25 years (Diehl et al. 1998; Ellsworth & Diehl, 1998).

Recent changes in Arizona's cotton production system, specifically pest management, renew discussion about this potentially devastating pest. Growers have spent considerable effort controlling other even more formidable pests since 1972, starting with bollworms and budworms (Heliothine complex) through the 1970's. The Heliothine complex became significantly less important starting in the 1980's up through today. Boll weevils came into prominence through the 1980's, but were eradicated in Arizona by the end of the decade (Antilla, pers. comm.). The decade of the 1990's has seen the introduction of two new sets of pest control technology that deal with one historic and one contemporary pest of AZ cotton. In 1996, transgenic Bt cottons were commercialized for the control of pink bollworm. At the same time, two new insect growth regulators (IGRs) for whitefly control were commercialized under Section 18 emergency exemptions (Ellsworth et al. 1996a,b; Ellsworth & Diehl, 1997). These powerful and selective technologies provided unparalleled levels of control and specificity in our system. By 1997, over half of Arizona's acreage was planted to Bt cotton and used one or more IGRs (Jones & Ellsworth, 2001).

These radical changes in pest management tools have had tremendous impact on the foliar insecticide requirements for Arizona cotton based on statewide statistics (Ellsworth & Jones, 2000). The average total number of foliar sprays over the last 15 years is about 7.3 for this state's cotton (Table 1). In contrast since 1997, this average has been cut in half. This trend in reduced insecticide use is bleakly contrasted to the requirements for *Lygus* control over these same periods. The number of sprays, the cost, and yield loss associated with this pest have risen dramatically in the last four years (Table 1). Even more disturbing is the doubling in the percentage of the total insect control budget dedicated to the control of this pest and the large increase in the share of insect yield loss attributable to *Lygus*. Growers are being forced to become as efficient and cautious with all variable inputs. The *Lygus* 'problem' for AZ growers is tantamount to a yearly tax of between 1–2 sprays or 20–35$/A, while still losing 2–5% of their yields to this pest in spite of these expenses!

The reasons for this trend are many and varied, but the relatively low spray environment that is fostered by the recent advances in PBW and whitefly management have increased the opportunity for *Lygus* to exploit Arizona's cotton crop and thus become the more ostensible target of foliar sprays by growers. As a major, yield-limiting pest and as a reducer of quality (Ellsworth, 2000), renewed efforts are needed to overcome this all too "familiar" pest. In 1997, studies of action levels for *Lygus* control were initiated and showed that the '15' level was broadly associated with maximum yields (Ellsworth et al. 1998). However, poor relationships were developed between bug density (especially adults) and yields. Thus, starting in 1999, a new series of studies were conducted where close examination of several different implementations of a '15' threshold could be accomplished (Ellsworth, 2000). This report examines the results from the 2000 growing season, the final year supported. Our goal is to precisely identify the optimal timing of chemical control measures that protect against yield loss while maximizing economic return.

Materials and Methods

Lygus thresholds (5) were evaluated in a *Lygus* management study at the University of Arizona's Maricopa Agricultural Center (Maricopa, AZ). *Lygus* populations were studied to evaluate the impact of various thresholds on cotton growth, lint quality, yield, turnouts and cost of insect management. This test was a randomized complete block design with 5 thresholds, 1 threshold planted at 3 densities, and one check. Each treatment was replicated four times in plots 18 rows (40 inch centers) wide by 60 ft. Sprays were timed according to thresholds that required a minimum of 15 total *Lygus* with varying numbers of nymphs per 100 sweeps. The five nominal thresholds, 15/0, 15/1, 15/4, 15/8 and 15/16, required 15 total *Lygus* with 0, 1, 4, 8 or 16 nymphs present per 100 sweeps, respectfully. Sprays against *Lygus* were only made when these levels were reached. The untreated check was never sprayed for *Lygus*.

The test was planted and hand-thinned to a density of 35,000 plants per acre (ppa). The 15/4 threshold (15/4-35) was also implemented on two higher plant densities: 55,000 ppa (15/4-55) and 75,000 ppa (15/4-75). These 3 plant densities were included within this study to examine the response of

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Lygus populations to different canopy conditions when subjected to the same thresholds and insecticides.

Each treatment was sprayed independently as determined by its nominal threshold but no sooner than six days after the previous spray. All treatments followed the same sequence of insecticides: Orthene® (1 lb ai / A), followed by Vydate C-LV® (1 lb ai /A), followed by Regent® (0.05 lb ai /A), and repeated as necessary. Insecticides were applied to respective treatments upon reaching the required threshold, usually within 24 hours as irrigation and weather permitted. Sprays were applied by ground using a John Deere® modified Hi-cycle® 600A, broadcasting with two nozzles per row (TeeJet Twinjet® 8003EVS) at 20 GPA.

An adjacent insecticide study evaluated alternative rotations of the three *Lygus* insecticides using a common threshold (15/4). Vydate C-LV (1 lb ai / A), Regent (0.05 lb ai / A) and Orthene (1 lb ai / A) were rotated in 3 sequences: V1 = Vydate, Regent, Orthene; R1 = Regent, Orthene, Vydate; O1 = Orthene, Vydate, Regent. This study was not sprayed for whiteflies, in spite of threshold-level populations.

Deltapine 33B was dry planted on 10 April and watered-up on 13 April. This variety is protected from lepidopteran pests by the Bollgard® gene. Early in the season cotton fleahoppers (*Pseudatomoscelis seriatus* Reutor) reached high levels of infestation and were treated on 30 June with a low rate of Vydate C-LV (0.15 lb ai / A). Whiteflies (*Bemisia tabaci* s.l.) reached threshold on 13 July and were treated with Knack® insect growth regulator (8 oz / A). The entire test received 1 Pix® plant growth regulator application on 14 July. On 7 July, 8 August, and 5 September, 5 representative plants per plot were mapped in treatments 15/4-35, 15/4-55, 15/4-75, and the untreated check. After harvest, final plant heights were recorded in all plots.

All plots were sampled a minimum of one time per week to properly time sprays. Samples were also taken 6 to 7 days after its last treatment (~7 DAT) to track population growth, and additional samples were taken as needed. Standard 15-inch sweepnets were used to take 25 sweeps per plot. Samples were bagged in plastic Ziplock® bags and frozen. After thawing, samples were inspected for *Lygus*. Adults, nymphs and other insects were counted. Examining sweep samples closely under a microscope made it easier to identify small insects and distinguish between small (1st, 2nd and 3rd instar) or large (4th and 5th instar) *Lygus* nymphs.

Cotton was defoliated on 5 September with Ginstar® (10 oz / A). On 18 September, 6 rows from each plot were machine harvested with a two-row picker, individually bagged and weighed. Subsamples were pulled and ginned in a one third, commercial-scale research gin to obtain turnouts. An additional two samples were removed from each subsample for fiber testing. Lint samples (ca. 25 grams) from each representative subsample were sent to the USDA classing office in Phoenix, AZ, and Starlab in Knoxville, TN, for HVI and other fiber testing.

Results and Discussion

The 2000 crop year was the second in a row of historically low insect pressures overall. About 2.8 sprays were made for all pests on average with only 2 sprays needed on *Bt* cotton (Ellsworth & Jones, 2000; Williams et al. 2001). *Lygus*, however, remained our number 1 pest for the fourth consecutive year. Nevertheless, with such a low pressure environment, only 1 spray was made against this pest on average, which compares favorably with the trends of the past four years (Table 1).

The study site selected at the Maricopa Agricultural Center (Maricopa, AZ) was specifically chosen for its propensity for experiencing damaging levels of *Lygus*. An abundance of alternate hosts are grown in the vicinity which likely help to support larger ambient densities of *Lygus*. Cultural practices and the seasonal dry-down period during early summer also serve to move *Lygus* to one of the only remaining hosts, cotton. Our test area was subject to timely and consistent *Lygus* pressure, typical of this area. The first threshold, 15/0, was initiated on 3 July, just 3 d later than in 1999, and required 5 sprays as compared to 7 in 1999 (Table 2). The last threshold, 15/16, was initiated on 18 July, a day earlier than in 1999, and in both years was sprayed 2 times. Thus, the seasonal dynamics were similar, yet not as severe as in 1999, and the pressures were slightly more compressed in time.

The spray sequence observed, Orthene fb Vydate fb Regent, in all thresholds (Fig. 1) did not bias interpretation of the thresholds under study based on the results in our adjacent rotational study. No significant differences were measured in that test where three different sequences of these chemicals were studied. Also, like 1999, no single active ingredient was used more than twice as recommended (Ellsworth et al. 1996b; Ellsworth, 1998), hopefully limiting any confounding effects of resistance development. Regent remains unregistered for use in cotton in this country; however, this active ingredient could be keystone in providing the alternative necessary to products threatened by FQPA and for avoiding resistances to already heavily-used *Lygus* insecticides. Acephate (e.g., Orthene) has been the #1 reported active ingredient used in Arizona cotton for the past 3 years (Agnew & Baker, 2001).

Measuring and evaluating differences among treatment regimes where insecticides are used so heavily and frequently poses unusual challenges in understanding *Lygus* dynamics (Fig. 2). One challenge is selecting one interval or protocol for drawing samples from the *Lygus* population that accurately reflect the "true" comparative dynamics there. The most common measure compares average densities over a regular interval, such as weekly. The difficulty comes in selecting the appropriate day of the week that does not bias individual treatment thresholds due to the proximity to a recent spray. One sample might be drawn shortly after a spray (4 DAT) thus showing greatly depressed *Lygus* activity for one threshold, while a comparative sample in a less intense regime may be up to 20 days after the last spray (Fig. 2). In addition to examining and comparing prespray levels through time, one solution is to fix the interval since the last spray and compare these samples (e.g., 7 days after treatment, 7 DAT). In these studies, we attempted comparisons of *Lygus* dynamics using each of these systems — weekly, prespray, and ~7 DAT means — which required more frequent bouts of sampling in all plots. For the UTC, we selected comparable sample dates in each case (Fig. 2).

The objective of this exercise is to attempt to capture information about *Lygus* dynamics that is more reflective of the outcome observed (i.e., yields). A yield depression has been seen in more aggressive *Lygus* treatment regimes in the past (Ellsworth et al. 1998; Ellsworth, 2000). The system which best mimicked this behavior of yields in 2000 was the post-spray averages (~7 DAT; Fig. 3). Here, the mean levels of nymphs, adults, and total *Lygus* revealed the most significant separation of treatments. There was great similarity among all treated regimes with all but the 15/16 threshold holding *Lygus* levels below the 15 total *Lygus* level at 7 DAT. However, there was a developing trend towards more *Lygus*, especially nymphs being present in the most aggressive thresholds, 15/0 and 15/1, at 7 DAT (Fig. 3). *Lygus* levels were at their lowest in the 15/4 and 15/8 thresholds which incidentally were triggered on the same dates and sprayed the same number of times in 2000 (Fig. 1; Table 2). Thus, in spite of 1 and 2 extra sprays over the 15/4 threshold, the 15/0 and 15/1 thresholds were left with more *Lygus* just 7 DAT.

Of course, no system of comparison in a study such as this, short of sampling every day, removes all bias of time or spray frequency. Fortunately, one of the principle variables of interest is yield. Each threshold can be compared directly (Fig. 4). Several striking aspects of this comparison can be seen. First, *Lygus* reduced yields by about 70% (1999) and 50% (2000) under the conditions of these tests. Second, even the most modest effort to control *Lygus* pays huge dividends; note the large increases in yields (1–1.5 bales / A) in the 15/16 threshold. Finally, statistically significant gains in yield were not observed beyond the 15/8 threshold. However, maximum yield ($Yield_{max}$) in each year was measured short of the most aggressive treatment regime (Fig. 4). This suggests that there was some sort of negative feedback process operating whereby additional sprays served only to depress yields. The potential mechanisms for this include phytotoxicity, secondary pest outbreaks, pest resurgence, resistance, plant compensation or response to "pruning," or some combination of two or more of these processes. The current study cannot absolutely rule out any one of these causes. However, several observations can be made. No apparent phytotoxicity was observed, though subliminal effects could have been operating. No secondary pests were present in sufficient density or distribution to cause yield differences—PBW and whiteflies were well-controlled. *Lygus* resurgence may be at work in this case based on the ~7 DAT means. The mechanism for this might be natural enemy destruction (data not shown) or differential resistances. The latter cause may be possible, though unlikely given the diversity and rotation of compounds used, the relatively small spatial scale involved, and the relatively high mobility of *Lygus* adults. Early pruning of fruiting forms by *Lygus* could have modestly stimulated yields, though we have no measurement of this potential phenomenon. It should be noted, however, that fruit retention in 2000 was exceptionally low during the early fruiting period across all thresholds (ca. 50%), making any differential stimulation of yields unlikely.

Because each year provides a background environment that controls yield potential and variation, it is useful to normalize data from each year, combine results over years (1999–2000), and model the responses of yield and revenue to the threshold levels tested (Fig. 5). Revenue, the second and more important, principle variable of interest, is defined as net income or revenue after subtracting *Lygus* control costs. Because the UTC was not a threshold per se, repeated regressions varying the nominal levels for UTC were made until a best fit was obtained (i.e., at 30 nymphs). The results for both variables show very strong and significant polynomial (order=2) fits. The rapid gains in yield, followed by a plateau and then slight decline, with decreasing numbers of nymphs (per 100 sweeps) are consistent with the observed yields for both years (Fig. 5). The maximum yield identified by this regression occurred at 15 total *Lygus* with 1.7 nymphs / 100 sweeps. This maximum, however, is not significantly different among the nominal levels of nymphs ranging from 0–8 / 100 sweeps. Put another way, from 0–5.4 nymphs / 100 sweeps represented only a 1% deviation from the maximum yields modelled.

The maximum economic return or revenue less *Lygus* control costs should be of most importance to growers. In this relationship (Fig. 5), the curve becomes even more arched showing a more rapid decline in profits after a maximum that is achieved at 15 total *Lygus* with 5.2 nymphs / 100 sweeps. This difference from the yield model is a reflection of the higher costs of maintaining more "protective" spray regimes. For example on average, only 3.5 sprays were required for the 15/4 threshold versus 6 sprays for the 15/0 threshold (Fig. 5). In the case of revenue, the 15/4 threshold produced the highest economic return with both higher (15/8 and 15/16) and lower thresholds (15/0 and 15/1) resulting in less money. Again looking at only a 1% deviation from the maximum revenue in this model, we can show that 1.9–8.5 nymphs are very similar in net returns to the grower. Data were collected on fiber qualities including micronaire (Fig. 5); however, this economic impact has not yet been quantified.

These results re-enforce the recommendation made over 20 years ago that nymphs should be present prior to initiating chemical control (Moore, 1978). However, a specific action level for *Lygus* control was not specified at that time except for damaged square levels. By 1984, Arizona was suggesting treatments once two consecutive samples exceeded 20 total *Lygus* per 100 sweeps. The specific role of nymphs was not mentioned (Flint et al. 1984). In 1994, Ellsworth et al. suggested action levels of 15–20 total *Lygus* / 100 sweeps as a supplement to a square damage survey and the presence of nymphs. It was not until relatively recently that specific levels of nymphs were mentioned as part of Arizona's recommendations (Diehl et al. 1998; Ellsworth & Diehl, 1998). They suggested that treating at 15–20 total *Lygus* with nymphs present, preferably 33% nymphs, provided the greatest likelihood of economic return. In California, the system incorporates square densities and fruit retention with *Lygus* counts. Flint et al. (1996) suggest 3 bugs per 50 sweeps (= 6 total *Lygus* / 100) with reduced fruit retention as an appropriate action level. However, they also state that these levels have not been verified with research under California conditions, and no specific reference is made to nymphs.

After the 1999 implementation of this experimental approach, Ellsworth (2000) introduced the '15/4' threshold (see Methods for description) that fully integrated counts of nymphs with the total numbers of *Lygus* found. The current work supports this generalized approach and re-inforces the importance of waiting until nymphs are present before spraying. Furthermore based on the modelling results, the 15/4 threshold would appear to be a prudent and convenient action level that will moderate spray frequency, maximize yields, and most importantly maximize profits. Further work is necessary on the relationship of these action levels with various aspects of plant phenology (e.g., square densities, fruit retention, plant population, etc.). These current recommendations are provided as a guide to producers who must also consider pest complex, production goals, and natural enemy populations.

Acknowledgments

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Table 1. Summary of Arizona statewide averages for foliar cotton insecticide use during the past 15 and 4 years. The total number of foliar sprays for all pests is contrasted against similar and additional statistics for *Lygus* bugs during the same period (Source: Ellsworth & Jones, 2000).

Years	1986–2000	1997–2000
Total Foliar Applications	7.34	3.68
No. of Applications	1.44	1.72
Cost ($)	19.64	33.40
% of Total Budget	21.66	44.70
Yield Loss (%)	2.47	4.01
% of Insect-Related Yield Loss	37.56	62.50

Table 2. Summary of threshold levels under study in 1999 & 2000, the number of sprays required, the associated costs for control (including application costs) and dates of initiation. Each candidate threshold required at least 15 total *Lygus* with the number of nymphs indicated per 100 sweeps before a spray was made.

Treatment	15/0	15/1	15/4	15/8	15/16	UTC
Threshold (Total **Lygus*****; Nymphs)***	≥ 15; 0	≥ 15; 1	≥ 15; 4	≥ 15; 8	≥ 15; 16	—
1999 Sprays (No.; date of 1st Spray)	7; 6/30	6; 6/30	4; 7/10	3; 7/16	2; 7/19	0
2000 Sprays (No.; date of 1st Spray)	5; 7/3	4; 7/10	3; 7/13	3; 7/13	2; 7/18	0
1999 **Lygus** ***Control Costs ($/A)***	120.51	105.50	67.75	52.75	34.75	0
2000 **Lygus** ***Control Costs ($/A)***	87.50	67.76	52.72	52.75	34.75	0

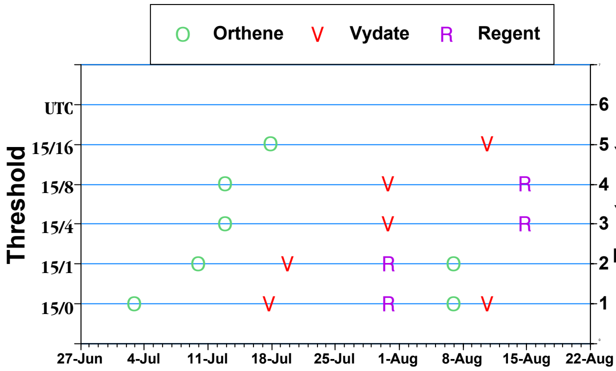

Figure 1. Timeline showing rotation and timing of insecticides used for control of *Lygus* for each threshold under study. All cotton was DP33B, sprayed once with Pix, and sprayed with an IGR for whiteflies.

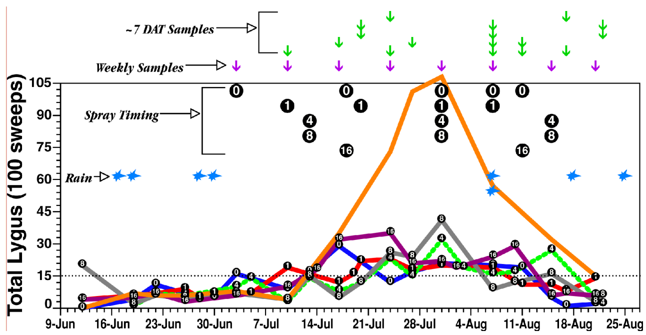

Figure 2. Total *Lygus* per 100 sweeps in 2000 threshold trial. The first set of arrows above the chart denote the frequency and timing of samples taken ca. 7 days after treatment (~7 DAT). The second set of arrows indicate the weekly samples. Numbered bubbles denote thresholds in nymphs / 100 sweeps: above, they indicate the frequency and timing of sprays; on lines, they match with their respective thresholds. Unnumbered line is the UTC. Grid-line is at 15 total *Lygus* / 100 sweeps.

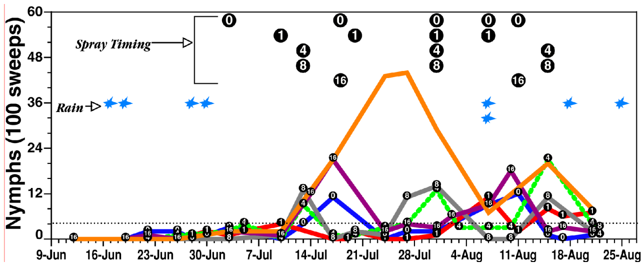

Figure 2 (continued). *Lygus* nymphs per 100 sweeps in 2000 threshold trial. Grid-line is at 4 nymphs per 100 sweeps.

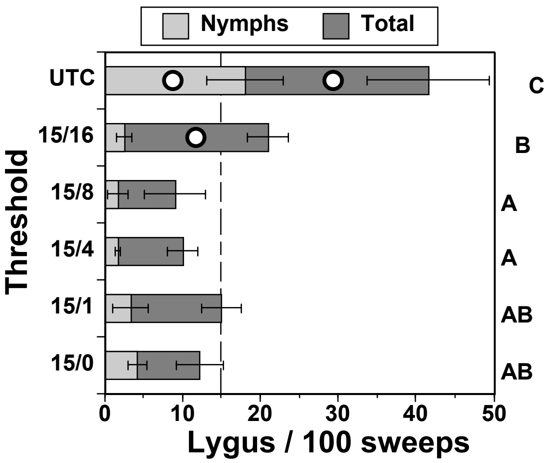

Figure 3. Average number of nymphs (±se), adults and total (±se) *Lygus* per 100 sweeps at ca. 7 days after treatment for each threshold. Bars (total *Lygus*) sharing the same letter are not significantly different (P < 0.05). Sections of bars with circle are significantly different from others within the same class (nymphs or adults).

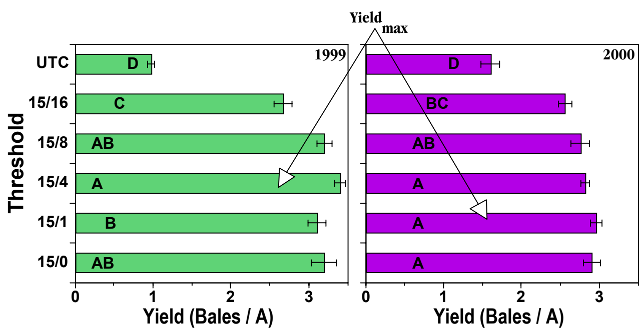

Figure 4. Average yields (±se) by threshold for 1999 (left) and 2000 (right). Maximum yield (Yield$_{max}$) was found at the 15/4 (1999) and 15/1 (2000) levels. Bars sharing the same letter are not significantly different within years (P < 0.05).

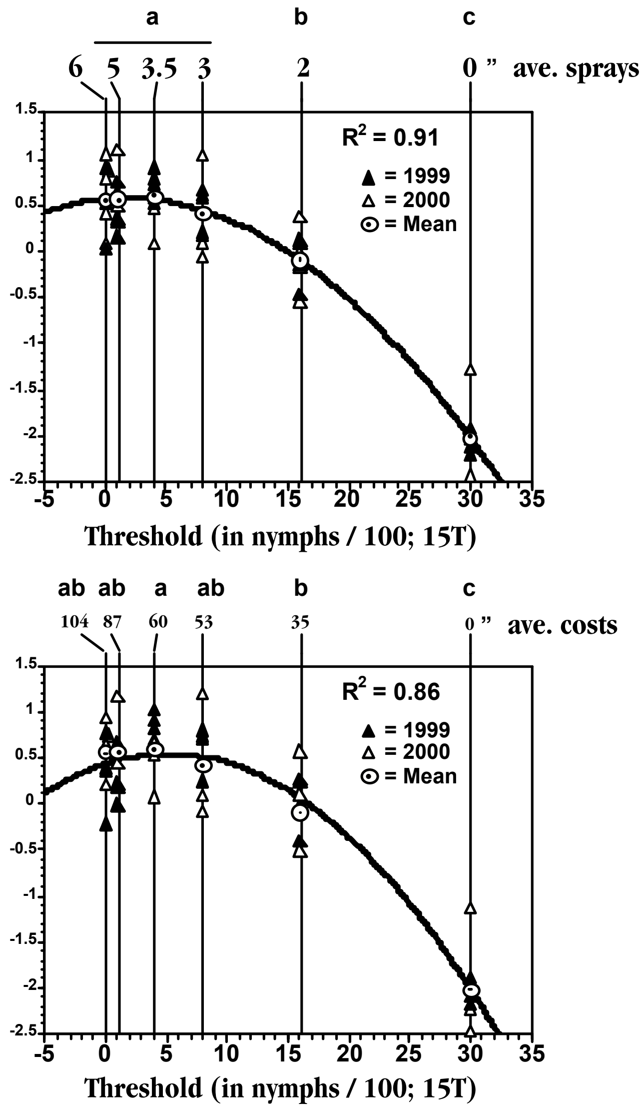

Figure 5. Relationships of normalized yields (top) and revenue after *Lygus* control costs (bottom) to *Lygus* thresholds (expressed in nymphs / 100 sweeps). Average number of sprays required (top) and *Lygus* control costs with applications ($/A; bottom) appear above each graph. Maximum yield occurred around 1.7 nymphs / 100 (1% range = 0–5.4), but maximum net return ($) was around 5.2 nymphs / 100 (1% range = 1.9–8.5). Average yields or revenues for each nominal threshold that share a letter (above each chart) are not significantly different from each other (Tukeys HSD; P < 0.05).