CULTURAL CONTROLS FOR THE MANAGEMENT OF *LYGUS* POPULATIONS IN COTTON

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ABSTRACT

We have attempted to review the potential and limitations of cultural approaches for control of *Lygus* populations in cotton, including management of alternate hosts and use of host plant resistance. Other than insecticides, cultural approaches seem the most likely of the currently available insect-management tactics to help in the management of *Lygus* populations. The use of transgenic or nectariless cotton cultivars that are resistant to *Lygus* could be easily implemented if they were available. Other kinds of cultural controls, such as management of alternate hosts, may not be adopted on a large scale unless they are part of an area-wide management program or until additional evidence of cost efficiency is demonstrated. Adoption of cultural approaches will be largely influenced by the availability and efficacy of alternative management practices, including insecticides, and other socioeconomic factors. Cultural approaches are best suited in "soft" systems, with low use of disruptive insecticides, where natural enemies are relied upon most heavily to maintain cotton pests below economically damaging levels.

INTRODUCTION

Plant bugs are an important pest of cotton in much of the U.S. Cotton Belt. The tarnished plant bug (TPB) and western tarnished plant bug (WTPB), *Lygus lineolaris* (Palisot De Beauvois) and *L. hesperus* Knight, respectively, are biologically similar species that cause comparable damage to cotton. The WTPB is the dominant species of *Lygus* found in cotton west of Texas, and TPB dominates in cotton from Texas to the East Coast, although other species of *Lygus* may occasionally be found in cotton (Jackson et al. 1998). Both the WTPB and the TPB are best known for causing the shedding of developing flower buds (squares) in cotton (e.g., Tugwell et al. 1976, Tingey and Pillemer 1977). However, damage to presquaring cotton and developing fruit (bolls) can also occur (Scales and Furr 1968, Hanny et al. 1977, Layton 1995). Plant bugs, including the cotton fleahopper (*Pseudatomoscelis seriatus* [Reuter]), have historically been recognized as one of the most important pest complexes in the U.S. Cotton Belt. *Lygus* spp. ranked as the third most damaging pests across the Cotton Belt in 1998 (Williams 1999).

Several recent events have elevated the level of awareness about *Lygus* in cotton, including heightened concerns about infestations in cotton after blooming has begun. First, eradication programs have eliminated the boll weevil, *Anthonomus grandis grandis* Boheman, as a key pest east of Mississippi, and on-going and impending eradication programs include most of the Mid South and much of Texas. Second, the occurrence of insecticide resistant populations of *Lygus* has been well documented over the last decade, especially in the Mid South (Xu and

Brindley 1993, Snodgrass and Elzen 1995, Snodgrass 1996). Third, there has been wide scale adoption of transgenic cotton expressing insecticidal proteins of *Bacillus thuringiensis* (Bt cotton) since its introduction to the commercial market in 1996 (Williams 1999). Bt cotton is especially valuable for the control of pink bollworms, *Pectinophora gossypiella* (Saunders), and insecticide-resistant tobacco budworms, *Heliothis virescens* (F.). Thus, the use of Bt cotton is often concurrently high in areas with a problematic history of *Lygus*, such as the Mid South and Arizona (Williams 1999), because these areas are also plagued by pink bollworms and tobacco budworms. Fourth, new insecticides introduced to control lepidopteran pests (e.g., Tracer®, Dow AgroSciences) are typically narrow in spectrum and have limited efficacy on most non-lepidopteran pests. The cumulative result of these changes has been a reduction in insecticide inputs that previously helped to suppress *Lygus* populations. Recent evidence indicates that *Lygus* populations will increase in cotton where fewer foliar applications of insecticides are made for other pests. Layton et al. (1998) reported increased levels of boll damage by TPB in Bt cotton fields compared with non-Bt cotton. Similarly, Stewart et al. (1998) found more TPB in Bt cotton than in non-Bt fields.

The changes outlined above have also renewed interests in non-insecticidal alternatives to control *Lygus* and prevent infestations in cotton. The WTPB and the TPB have a wide range of host plants (Scott 1977, Snodgrass et al. 1984a, Young 1986), and cotton is generally considered, at best, a mediocre and moderately attractive host for these species relative to many other hosts (e.g., Fleischer and Gaylor 1988, Craig 1998). Intuitively, it seems plausible that managing relatively attractive alternate hosts or reducing the quality of cotton as a host are potential ways to manipulate *Lygus* populations and reduce their impact in cotton. Several cultural methods of plant bug management have been investigated since the 1960's. Our purpose is to review past and current research involving cultural approaches for managing *Lygus* populations, including the management of alternate host plants and host plant resistance factors which make cotton less preferred or tolerant to *Lygus*. We will also address the potential and limitations of cultural approaches for managing plant bugs.

MANAGEMENT OF *LYGUS* HOST PLANTS

Cotton-Alfalfa Intercropping. Probably the most common cultural approach suggested for the management of *Lygus* in cotton is the intercropping of alternate crops that are more attractive than cotton. In western cotton, alfalfa has often been suggested as such an alternative. The choice of alfalfa is a result of its strong attractiveness to *Lygus* when compared with cotton (Sevacherian and Stern 1974, 1975; Cave and Gutierrez 1983). Also, alfalfa is a marketable and readily cultivated crop in the western Cotton Belt, and when grown as a forage crop, can tolerate large populations of *Lygus* without significant injury. Because large plantings of alfalfa are grown in close proximity to cotton in parts of the West, most research with a cotton-alfalfa intercropping for plant bug management has involved the WTPB.

Alfalfa grown for hay is typically mowed one or more times during the cotton season. By harvesting strips of alfalfa at several week intervals, parts of a field can be maintained in an attractive state to provide a lasting alternative host for *Lygus*. Several studies have indicated that strip harvesting alfalfa fields (or alfalfa interplanted with cotton) maintains WTPB populations in the alfalfa, preventing their exodus to surrounding crops (Stern et al. 1964, 1969; Sevacherian and Stern 1975; Summers 1976; Godfrey and Leigh 1994). For example, Rakickas and Watson (1974) demonstrated the movement of the WTPB among alternate strips of strip-harvested alfalfa such that overall populations within the alfalfa field remained relatively stable (Fig. 1). Mowing caused significant mortality of *Lygus* nymphs, whereas adults clearly moved to uncut strips. In addition to *Lygus*, some natural enemy populations are also maintained in strip harvested alfalfa versus solid harvested (e.g., Rakickas and Watson 1974, Summers 1976, Fig. 2), and thus, the alfalfa may serve as a refuge for beneficial arthropods.

Alfalfa as an intercrop for cotton has also been investigated as a means of managing the TPB. In Mississippi, Schuster (1980) concluded that alfalfa interplanted with cotton could potentially reduce TPB populations in the adjacent cotton. He also observed increases in some predatory insect populations in cotton adjacent to alfalfa. No effects on cotton fleahopper populations were observed. However, the utility of alfalfa as an intercrop in the Mid South is questionable because of agronomic and economic limitations of growing this crop.

Strong empirical evidence is lacking to show that plant bug numbers are reduced in cotton adjacent to strip harvested and interplanted alfalfa. This would likely require replication of cotton fields next to alfalfa versus those not near alfalfa, and the demonstration that numbers of plant bugs are lowered in cotton adjacent to alfalfa. The maximum distance that alfalfa can be located from cotton and still impact *Lygus* pcpulations in cotton remains unknown, so the scale needed for such experiments is unknown and may restrict their feasibility. However, existing data are circumstantially convincing that alfalfa maintained in an attractive state will reduce colonization of *Lygus* in nearby cotton.

Trap Crops. Applying insecticides to alternate hosts that harbor large populations of *Lygus* has also been investigated as a means of reducing their subsequent movement into cotton. As with intercropping alfalfa, initial investigations with trap crops were done with the WTPB. Mueller and Stern (1973) and Sevecharian et al. (1977) described the amassing of *Lygus* in safflower and a mechanism for timing insecticide treatment to this crop based on heat unit accumulation (degree days) to reduce WTPB colonization in cotton. These data suggest that

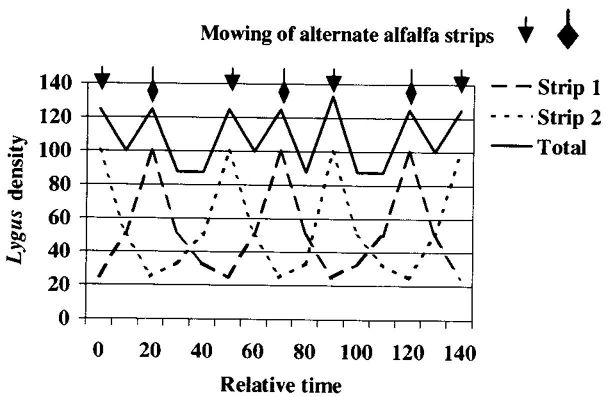

FIG. 1. Representation from Rakickas and Watson (1974) showing *Lygus* movement between alternate strips of alfalfa in strip harvested fields, reducing their movement to sensitive crops.

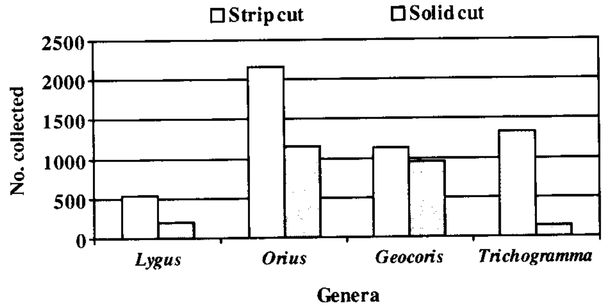

FIG. 2. Numbers of selected insects collected from strip harvested versus solid harvested alfalfa fields (from Summers 1976).

insecticidal treatment of safflower for *Lygus* was more economical than treating subsequent infestations in cotton. As with the studies of alfalfa-cotton interplantings, the data were somewhat circumstantial but overall are largely convincing.

Recent work has attempted to document the effectiveness of interplanting several alternate hosts within cotton fields, in combination, not only as a potential trap for TPB but also as a refuge for tobacco budworms and cotton bollworms, *Helicoverpa zea* (Boddie), that would be susceptible to the delta endotoxin produced in the surrounding Bt cotton (Craig 1998, Craig et al. 1999). Because of their ease of establishment and attractiveness to TPB, kenaf and redroot pigweed (*Hibiscus cannabinus* [L.] and *Amaranthus retroflexus* [L.], respectively) were two of four species selected for testing in this multispecies interplanting. In each test field, one-half of the interplanting was periodically sprayed with insecticide to remove TPB. These data indicated that although these hosts were relatively preferred to cotton for at least part of the growing season, TPB still reached treatment levels in the surrounding cotton during one year of the study (Craig et al. 1999). Insecticide applications to the interplanted hosts caused a reduction in the number of TPB in the adjacent cotton during this same year. This suggests that the alternate hosts acted as a nursery for TPB, and treatment of the trap with insecticide may be necessary to avoid dispersal into cotton.

Destruction or Management of Non-crop Host Plants. A number of studies have documented the sequence and movement of *Lygus* among its hosts, particularly with the TPB (e.g., Fye 1975, Khattat and Stewart 1980, Cleveland 1982, Anderson and Schuster 1983, Snodgrass et al. 1984b, Fleischer and Gaylor 1987). The array of alternate hosts for *Lygus* poses both an opportunity and a challenge when cultural methods of control are considered. It would seem a virtual impossibility to eliminate *Lygus* populations via destruction of alternate hosts, but Fleischer et al. (1989) and Snodgrass and Stadelbacher (1994) suggested the possibility of reducing *Lygus* colonization in cotton by management of key roadside and other non-crop hosts. Mowing or herbicide applications would target spring host plants to prevent the development of large populations in an area. Mowing or maturation of alternate *Lygus* hosts can force resident populations into adjacent crops (e.g., Fleischer et al. 1988). For this reason, producers are cautioned to avoid physical or chemical destruction of nearby alternate hosts during periods when the adjacent cotton is susceptible to TPB injury (Layton 1999). However, properly timed management of alternate hosts could presumably reduce movement into cotton. Herbicides can be used to reduce populations of key hosts (Fleischer et al. 1989), but a reduction in *Lygus* populations in cotton resulting from destruction or management of non-crop hosts has not been conclusively demonstrated. Current research (Snodgrass, pers. comm.) is investigating the potential for area wide destruction of non-crop spring hosts as a means of reducing TPB populations that subsequently infest cotton. Definitive results from these experiments are not yet available.

HOST PLANT RESISTANCE (HPR)

Comprehensive information on HPR to insects in cotton, including resistance to plant bugs, can be found in Maxwell and Jennings (1980), Matthews and Tunstall (1994) and references therein. This paper will highlight the more notable plant characteristics that impart resistance of cotton to *Lygus* with special reference to their potential as cultural control tactics.

Antibiotic and Antixenotic Traits. The most celebrated of the host plant resistance factors for *Lygus* is a trait where extrafloral nectaries are not produced by cotton (i.e., nectariless cotton). Because only floral nectar is available to insects on nectariless cotton, neither pests nor their natural enemies have access to nectar prior to flowering unless it is available from non-cotton sources. A number of studies have documented the negative impact of nectariless cotton cultivars on *Lygus* populations (e.g., Tingey et al. 1975; Schuster et al. 1976; Calderon 1977; Henneberry et al. 1977; Kitten 1979; Benedict et al. 1981; Bailey et al. 1980, 1984; Bailey 1982; Scott et al. 1988; Platt and Stewart 1999). The reduction in *Lygus* populations on nectariless cotton is typically reported in the range of 30-60%. Several studies have also noted negative impacts on other cotton pests, primarily lepidopterans (e.g., Lukefahr and Rhyne 1960, Lukefahr et al. 1965, Davis et al. 1973, Benschoter and Leal 1974, Wilson and Wilson 1976, George et al. 1977, Henneberry et al. 1977, Beach et al. 1985, Flint et al. 1992, Naranjo and Martin 1993), and also on beneficial arthropods (e.g., Schuster et al. 1976, Calderon 1977, Henneberry et al. 1977, Lingren and Lukefahr 1977, Kitten 1979, Adjei-Maafo and Wilson 1983, Scott et al. 1988). Most recently, Platt and Stewart (1999) documented increased plant protection, in the form of increased square retention (Fig. 3) and yield, of nectariless cultivars in the presence of high populations of TPB when compared to near-isogenic nectaried cultivars.

The reduction in *Lygus* numbers on nectariless cotton appears to result from both negative impacts on development and survival (i.e., antibiosis) and a non-preference for feeding and oviposition (i.e., antixenosis). In cage studies with near isogenic genotypes, Schuster et al. (1976) documented a clear ovipositional non-preference by TPB to nectariless cotton verses a nectaried cultivar (Fig. 4). Benedict et al. (1981) found reduced survival of adult *Lygus* on some nectariless cultivars compared with their nectaried counterparts. A few studies (e.g., Scott et al. 1988) have suggested that the impact of nectariless cotton on TPB populations diminishes as field size increases. A breakdown in the effectiveness of a non-preference for nectariless cotton by *Lygus* may occur in the absence of more attractive cotton cultivars.

Several other plant characters have been implicated in conferring to cotton some level of protection to plant bugs. Both smoothleaf (glabrous) and extremely pubescent cotton genotypes have may have some resistance to plant bugs, however, reduced trichome density has more often been noted for its susceptibility to plant bugs (Laster and Meredith 1974, Bailey 1982). Frego bract cultivars, although non-preferred by boll weevils (Hunter et al. 1965, Jenkins et al. 1973), have been shown to be more sensitive to *Lygus* injury (Laster and Meredith 1974, Bailey et al. 1980).

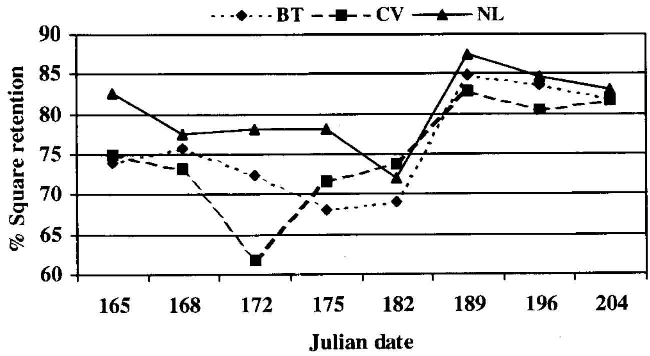

FIG. 3. Percent square retention of nectariless cotton (NL) versus Bt-transgenic nectaried (BT) and non-Bt nectaried (CV) cotton (from Platt and Stewart 1999). Cultivars were near isogenic lines of Deltapine 5415.

Tolerance. An impressive number of experiments have investigated cotton's tolerance to early-season abscission of squares including Eaton (1931), Hamner (1940), Gilliland (1972), Rahman (1977), Stewart et al. (1989), Mulrooney et al. (1992), Terry (1992), Montez and Goodell (1994) and Ihrig et al. (1996). These studies involve manual removal of squares and generally imply that cotton can compensate for a considerable amount of prebloom square loss without significant reduction in yield or delays in crop maturity. Indeed, low to moderate levels of square loss sometimes increased yield. For example, Stewart et al. (unpublished) showed an increase in yield when all squares initiated during the first week of squaring, representing about 20% of the total prebloom square production, were removed from plants (Fig. 5), and a corresponding delay in maturity was not observed. Brook et al. (1992b) showed a similar yield increase following early damage. An overview of the literature suggests that when high levels of prebloom square loss occur, particularly over an extended period of time, the probability of a significant yield reduction and delays in crop maturity increases dramatically.

A few studies have used naturally occurring or artificial infestations of *Lygus* to cause injury to cotton (e.g., Jubb and Carruth 1971, Black 1973, Tugwell et al. 1976). Collectively, these also show cotton can tolerate at least moderate levels of damage inflicted by plant bugs, but severe levels of damage can result in maturity delays and yield reduction. These studies also indicate that the timing of infestation, as related to plant development, can greatly affect the impact on plant growth, yield and maturity.

Most of the above studies illustrate cotton's ability to compensate for square loss but do not demonstrate tolerance in the sense of HPR where certain genotypes are more or less sensitive to injury. The few studies that do address this issue have rarely used near isogenic cultivars. However, Laster and Meredith (1974) demonstrated a potential method for identifying genetic resistance to *Lygus*, and their data indicated different susceptibilities of cotton cultivars to the TPB. Mann et al. (1997) was able to show that different genotypes of cotton , characterized

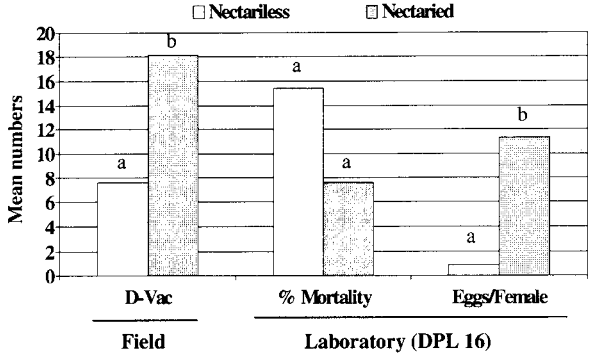

FIG. 4. Average numbers of TPB in D-Vac samples of field plots of nectariless and nectaried cotton (1974 data), and mortality and fecundity of adult females caged on cotton with and without nectaries over a 14-d period (paired bars with different letters are significantly different, Students t-test, $P<0.05$; from Schuster et al. 1976).

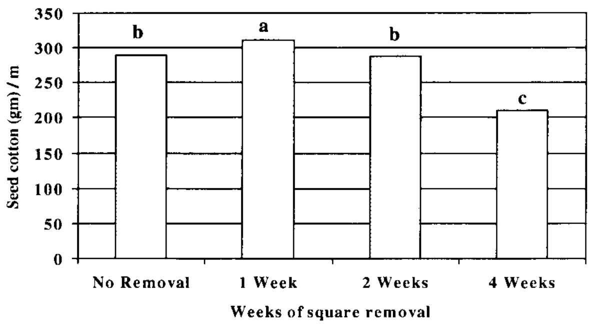

FIG. 5. Average yield of three different cultivars of cotton, for two years, when 100% of squares were removed at 1, 2 and 4 weeks after square initiation (bars without a common letter are significantly different, LSD, $P<0.05$; from S. D. Stewart, unpublished).

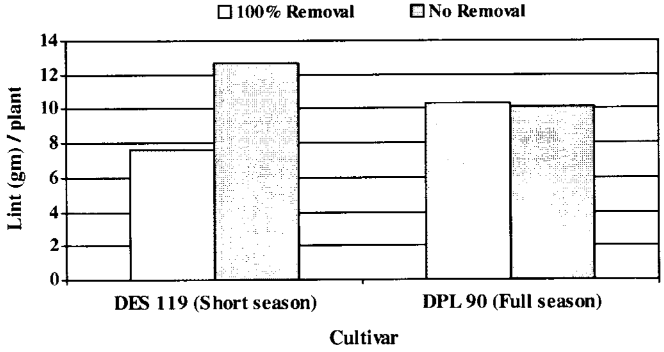

FIG. 6. Response of a short and full season cultivars to 100% removal of early-season squares for three weeks in late planted and irrigated cotton (1993 data, from Mann et al. 1997).

primarily as early versus late maturing cultivars, varied in their susceptibility to square loss. Early maturing cultivars were more sensitive to square loss than later maturing cultivars, at least in some environments (Fig. 6), but both irrigation and planting date were factors which interacted with the amount of square loss to influence the cottons' response to injury. Brook et al. (1992a,b) also showed that some varieties were better able than others to tolerate early square loss and insect infestations.

ADOPTION AND IMPLEMENTATION OF CULTURAL CONTROLS

The successful adoption of cultural controls for *Lygus* has not occurred on a wide scale, although some nectariless cotton varieties were popular in the early 1980's. The availability of cheap, broad spectrum and effective insecticides is a dominant factor that has retarded the development and implementation of effective cultural controls. Historically, cotton has been intensively sprayed with insecticides for a multitude of pests, and *Lygus* populations were often suppressed coincidentally. In the Bt transgenic, boll weevil free environment currently evolving in much of the U.S. Cotton Belt, natural enemies will almost certainly have increased value in preventing outbreaks of at least some pests. In such an environment, cultural controls for *Lygus* should have greater value. Also, alternative management tactics will become more attractive if resistance to insecticides in *Lygus* populations expands.

The use of trap cropping and intercrops, as Schuster (1980) pointed out, will be limited by the ease of establishing and managing alternate hosts, their efficacy in manipulating *Lygus* populations, and the value of the trap. It seems unlikely that a trap with little or no inherent value, other than for plant bug control, will be adopted by producers unless it is highly effective or no alternative control approaches are available. The managing of non-crop hosts may need to be carried out on a regional basis to maximize the impact on *Lygus* populations and increase cost efficiency. This approach may require a synchronized and legislated program. The ecological and environmental consequences of this type of regional management are poorly understood, and the potential for adverse consequences must be considered.

Resistant genotypes of cotton could be readily adopted if pursued by the seed industry, but nectariless cotton varieties are not currently available for large plantings on commercial acreage. There appears to be no negative agronomic traits associated with the nectariless character (Meredith et al. 1973, Meredith 1980). However, there are clearly negative impacts on certain predatory arthropods and parasitoids. It is unclear whether any negative effects of the nectariless trait on beneficial arthropods would be offset by increased plant protection from plant bugs and less disruption of beneficial arthropods with insecticides. Other *Lygus* resistant traits appear to have a trade-off of positive and negative attributes. For example, cultivars with relatively high trichome density are more attractive to tobacco budworm and cotton bollworm (Lukefahr et al. 1965, 1971, 1975; Robinson et al. 1980). None of the currently known traits that impart resistance of cotton to *Lygus* are expected to be "silver bullets", and thus, the seed industry has a limited entrepreneurial incentive to pursue their incorporation into commercially available cultivars. The current transgenic revolution may create cotton cultivars that are highly-resistant to plant bugs, in which case, the cost of such technology would determine its value as a *Lygus* management tool.

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