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Late-season Insect Pests of Soybean in Louisiana:

Preventive Management and Yield Enhancement

Melissa M. Willrich, David J. Boethel, B. Rogers Leonard,
David C. Blouin, Bentley J. Fitzpatrick and Robert J. Habetz

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Introduction

Late-season Insect Pests

The velvetbean caterpillar, *Anticarsia gemmatalis* Hübner, and the soybean looper, *Pseudoplusia includens* (Walker), are important pests of soybean, *Glycine max* (L.) Merrill, in Louisiana. These species migrate from Central and South America and occur at damaging densities from early to mid-August through September. Both pests injure soybean foliage and often occur simultaneously in fields.

The velvetbean caterpillar can strip fields of foliage within five to seven days when populations are at high levels (Herzog and Todd 1980). An individual soybean looper larva can consume 200 cm^2 of soybean foliage (Kogan and Cope 1974), with the 6^{th} larval stadia consuming 68% of the total leaf area lost (Reid and Greene 1973). Losses from the soybean looper in Louisiana are an estimated 16.4% of the total harvestable seed yield (Bergman et al. 1985). Larval populations of soybean looper in Louisiana are larger in soybean grown in cotton agroecosystems than in soybean grown in other agroecosystems (Burleigh 1972), and velvetbean caterpillar are most damaging in southern regions of the state (Newsom et al. 1975) (Table 1).

In addition to velvetbean caterpillar and soybean looper, a soybean stink bug complex consisting of southern green stink bug, *Nezara viridula* (L.), and brown stink bug species, *Euschistus servus* (Say) and *E. quadrator* Rolston, must be managed in late-season soybean production systems. Stink bugs are damaging as both nymphs and adults, preferring to pierce and feed on fluids of developing seed. They account for an estimated $68 million or more in insecticide costs and crop damage in some years in the southern states (McPherson et al. 1994). These late-season soybean insect pests create the need for the continuous development of insecticide programs that are cost effective, maintain profitable yields and conserve natural enemies.

Table 1. Percent of acreage treated for control of soybean looper and velvetbean caterpillar, and the percent of acreage planted for designated soybean maturity groups for 1999 and 2000 in Louisiana.[1]

Region of Louisiana	% Acreage treated[2]				% Acreage planted per soybean maturity group								Total acreage planted[3]	
	Soybean Looper		Velvetbean Caterpillar		IV		V		VI		VII			
	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
South[4]	16.0	12.0	33.5	28.0	24.0	25.5	54.5	53.5	19.0	20.5	2.5	<1	385,589	377,542
Northeast[5]	46.0	35.0	4.0	2.0	37.0	50.0	53.0	44.0	9.0	5.0	1.0	<1	498,900	431,773

[1] Data provided by Dr. Jack Baldwin, entomologist, Louisiana Cooperative Extension Service.
[2] In 2000, 16% of the acreage in south Louisiana applied Dimilin at the R2 to R3 growth stage. Late-season insecticide applications for velvetbean caterpillar were probably not necessary on those acres.
[3] In both years, data are estimates that represent approximately 94% of Louisiana soybean acreage.
[4] Includes southwest and southcentral Louisiana and represents the following parishes: Acadia, Jeff Davis, Vermilion, Iberville, St. Martin, Rapides, St. Landry, Avoyelles, Pointe Coupee and Evangeline.
[5] Includes the cotton-soybean agroecosystem and represents the following parishes: Franklin, Morehouse, West Carroll, Concordia, Catahoula, Madison, Richland, Ouachita and Tensas.

Diflubenzuron: Insecticide Efficacy

Diflubenzuron (Dimilin) is an insect growth regulator (IGR) with a mode of toxicity that inhibits chitin formation in an insect's exoskeleton (Bass et al. 1980). Because mortality is not immediate, diflubenzuron appears most effective in preventive applications on soybean, before the insect pest arrives in the field. Sprays are timed when soybean plants reach the R2 to R3 growth stages (Fehr et al. 1971). Diflubenzuron, applied at rates of 0.0313 and 0.0626 lb ai/acre (2 and 4 ounces formulated product/acre), has been effective in the control of the velvetbean caterpillar in numerous states and countries including Georgia, South Carolina and Brazil (Turnipseed et al. 1974), Texas (Way et al. 1995), Florida (Funderburk et al. 1989) and Louisiana (Layton and Boethel 1986). Crowe (1995) observed control for up to 21 days after treatment, and Boethel (1986) reported highly efficacious control for 54 days after treatment. The ability of diflubenzuron to remain effective for this length of time is because of chemical properties of the diflubenzuron molecule, including low water solubility and binding affinity for the lipophilic components of the plant cuticle (McDonald and Weiland 1995). Further research is needed to compare preventive diflubenzuron applications with Louisiana's current velvetbean caterpillar control recommendations that are based on population monitoring and therapeutic treatments applied when economic thresholds are exceeded.

Planting of maturity group IV soybean cultivars has increased in the southern United States because early-planted, early-maturing cultivars avoid late-summer droughts, insect infestations and poor harvest weather (Boquet 1994). In a Georgia study, cultivars from maturity groups IV through VIII were routinely monitored to determine the effect of plant maturity on the abundance of velvetbean caterpillar, and it was concluded that maturity groups IV and V had lower overall infestation levels (McPherson et al. 1996). Determination of velvetbean caterpillar occurrence in soybean maturity groups traditionally grown in Louisiana is critical if a preventive management strategy that uses diflubenzuron becomes a management recommendation by the Louisiana Cooperative Extension Service.

While diflubenzuron has proven effective against velvetbean caterpillar, it historically has suppressed only soybean looper infestations. Populations of small soybean looper larvae have been significantly reduced 14 days after treatment with diflubenzuron applied at 0.0939 lb ai/acre (6 ounces formulated product/acre) in a Georgia study (McPherson and Moss 1990). Diflubenzuron also has demonstrated the ability to slow soybean looper larval development (Felland and Pitre 1989). Larvae in the 3rd and 4th instars were more numerous in diflubenzuron-treated plots, and nontreated plots contained larger proportions of 5th and 6th instars seven days after treatment. Finally, consumption of sub-lethal doses of diflubenzuron on foliage slowed larval development; therefore, even if soybean loopers did not die, their potential for damaging the crop was reduced (Bass et al. 1980).

Diflubenzuron has been reported to give variable results in the control of the soybean stink bug complex. In particular, diflubenzuron was shown to be ineffective against the southern green stink bug and the brown stink bug (Boethel 1986, McPherson and Gascho 1999). Hudson and Clarke (1997) reported stink bug populations in diflubenzuron-treated plots were lower than in nontreated plots, with suppression believed to be associated with increased predation and parasitism and not direct lethality to the target insects. It has been suggested that certain groups of insects, according to their feeding habit, escape intoxication because diflubenzuron is not systemic; therefore, piercing-sucking insects such as stink bugs should not be affected (Mulder and Gijswijt 1973). These conflicting observations justify the need for additional research into the effect of diflubenzuron on the soybean stink bug complex.

Soybean looper, *Pseudoplusia includens*, larvae feeding on soybean.

Diflubenzuron: Yield Enhancement

Reports in the last 10 years from southern soybean-producing states indicate yield increases from the preventive co-application of diflubenzuron and boron. Georgia's Cooperative Extension Service has recommended applying diflubenzuron and boron at 0.0313 and 0.2 lb ai/acre (1 lb formulated product/acre), respectively, at the R2 to R3 growth stage for yield enhancement (Hudson 1998). The rationale for applying boron with diflubenzuron relates to boron's positive influence on flower pollination and seed set. The timing of diflubenzuron applications occurs at the stage of boron use, hence the two compounds are applied simultaneously. Field tests conducted on loamy Georgia soils showed overall seed yield enhancement of about 6.5 bu/acre above the nontreated plots, representing a positive net economic return for the total investment of approximately $136/acre (McPherson and Gascho 1999). Yield increases of one to three bu/acre also have been reported on Georgia sandy soils when boron is applied at 0.05 to 0.22 lb ai/acre (0.25 to 1.1 lb formulated product/acre) to soybean foliage (Hudson 1998). Yield responses have been best correlated with seed weight and less correlated with seed number (Gascho and McPherson 1997). Additionally, Dimilin 2 Liquid is labeled for enhancing yields in the absence of significant insect pressure (Anonymous 1999). In contrast to field results from Georgia, a study conducted in Mississippi on both sandy and clay soils, in which soybeans were both irrigated and non-irrigated, demonstrated that diflubenzuron (0.0313 lb ai/acre) and boron (0.25 lb ai/acre) did not significantly improve soybean yields (Zhang 2001).

These Georgia studies have appeared in numerous popular press articles reporting the benefits of diflubenzuron and boron for yield enhancement. Because soybean growers outside of Georgia have become aware of these articles, additional research is needed to substantiate their findings for other geographical locations. Questions remain as to whether diflubenzuron, boron or the combination of both influence soybean yield.

Soybean Integrated Pest Management (IPM)

Diflubenzuron is not recommended universally for Louisiana soybean production because it is used preventively, before velvetbean caterpillars appear in the field. Insecticide applications made in this manner are generally avoided because economic threshold levels, a foundation of IPM, are not considered. Preventive insecticide programs with less selective compounds characteristically have resulted in pest resurgence and pesticide resistance (Pedigo 1992). Although negative effects have resulted from using prophylactic treatments, IGRs may have a place in some IPM systems. IPM approaches are intended to combine methodologies that are practical, effective, economical and protective of both public health and the environment (Smith et al. 1976). IGRs have potential in IPM because of their safety and toxicity to specific insects (Metcalf 1980). If Louisiana soybean fields consistently receive significant soybean looper and velvetbean caterpillar populations, a preventive pest management strategy should be considered.

Diflubenzuron should be compared to other registered insecticides and to the experimental IGR, methoxyfenozide (Intrepid). This insecticide acts as a nonsteroidal ecdysone agonist in lepidopteran, dipteran and coleopteran larvae (Dhadialla et al. 1998, Oberlander et al. 1998). Methoxyfenozide has demonstrated successful control of soybean looper and velvetbean caterpillar in field studies in Louisiana (Mascarenhas 1997, Fitzpatrick et al. 1999, Fitzpatrick et al. 2000b).

Objectives

The objectives of this research were:

1) to determine the effectiveness of the insect growth regulators, diflubenzuron and methoxyfenozide, as management strategies for a late-season soybean insect complex in Louisiana that includes velvetbean caterpillar, soybean looper and the stink bug guild,

2) to determine the occurrence of velvetbean caterpillar and soybean looper in different soybean maturity groups commonly grown in Louisiana and under what circumstances a preventive management program that uses diflubenzuron be considered for insect management and

3) to determine the effect of diflubenzuron, in combination with boron, for yield enhancement in soybeans absent of insects.

Insect Growth Regulators as Preventive Management Strategies for a Late-season Soybean Insect Pest Complex

Objective

To determine the effectiveness of the insect growth regulators, diflubenzuron and methoxyfenozide, as management strategies for a late-season soybean insect complex in Louisiana that includes velvetbean caterpillar, soybean looper and stink bugs.

Materials and Methods

Locations. Field studies were conducted during the summers of 1999 and 2000 at the Rice Research Station in southwest Louisiana near Crowley (Acadia Parish); at the Macon Ridge Location, Northeast Research Station, near Winnsboro (Franklin Parish); and at the Central Research Station, Ben Hur Farm, near Baton Rouge (East Baton Rouge Parish).

Insecticide treatments and application. Insecticides evaluated during the two years included diflubenzuron (Dimilin 2 Liquid, Uniroyal Chemical Co., Middlebury, Conn.), boron applied as disodium octaborate tetrahydrate (Solubor 20.5 Wettable Powder, U.S. Borax, Valencia, Calif.), diflubenzuron + boron tank mixture, methoxyfenozide (Intrepid 80 Wettable Powder, Intrepid 2 Flowable, Rohm & Haas Co., Philadelphia, Pa.), thiodicarb (Larvin 3.2 Flowable, Aventis, Research Triangle Park, N.C.), spinosad (Tracer 4 Flowable, Dow AgroSciences, Indianapolis, Ind.) and *lambda*-cyhalothrin (Karate-Z 2.08 Capsule Suspension, Syngenta, Wilmington, Del.). Not all insecticides were applied in every year and at every location.

Insecticide treatments at Ben Hur and Crowley were applied with a hand-held CO_2 sprayer calibrated to deliver 15 GPA at 30 psi through TeeJet 8002 flat fan nozzles (two/row). Treatments at the Northeast Research Station in Winnsboro were applied with a tractor-mounted sprayer and compressed air system calibrated to deliver 15 GPA through TeeJet 80015 flat fan nozzles (two/row) at 32 psi.

Crowley Study. In 1999, plots were 59 feet by 12 rows (30-inch row spacing) and arranged in a randomized complete block design with four replications. Diflubenzuron (0.0313 lb ai/acre) was applied at the R2 to R3 growth stage (July 15, 1999) to 'Asgrow 6101RR' (maturity group VI) soybeans, planted May 25, 1999. Nontreated control plots also were included.

In 2000, plots were 70 feet long by eight rows (30-inch row spacing) and arranged in a randomized complete block design with four replications. Diflubenzuron (0.0313 lb ai/acre) and methoxyfenozide (0.125 lb ai/acre) were applied at the R2 to R3 growth stage (July 6, 2000) to 'Asgrow 6101RR' (maturity group VI) soybeans planted May 16, 2000. Nontreated control plots also were included. In both years, an additional treatment was considered for as-needed control of velvetbean caterpillar and/or soybean looper; however, because of small populations, the treatment was not applied. Seed yields in 1999 and 2000 were determined by harvesting eight and two rows, respectively, per plot with an Allis Chalmers Gleaner K2 combine and correcting to 13% moisture.

Winnsboro Study. In 1999, plots were 55 feet long by four rows (40-inch row spacing) and arranged in a randomized complete block design with five replications. Four treatments were evaluated. Preventive treatments applied at the R2 to R3 growth stage (August 3, 1999) to 'Buckshot 66' (maturity group VI) soybeans planted June 3, 1999, included diflubenzuron (0.0313 lb ai/acre) and methoxyfenozide (0.125 lb ai/acre). Thiodicarb (0.45 lb ai/acre) was applied as needed at the economic threshold (September 14, 1999) of soybean looper. The study included a nontreated control.

In 2000, two studies were conducted and plots were 58 feet long by four rows (40-inch row spacing) and arranged in a randomized complete block design with five replications. Preventive treatments in both studies were applied at the R2 to R3 growth stage (August 4, 2000) to 'Pioneer 9631' (maturity group VI) soybeans planted May 30, 2000. Six treatments were evaluated during study I. The three treatments applied preventively included diflubenzuron (0.0626 lb ai/acre), methoxyfenozide (0.125 lb ai/acre) and methoxyfenozide (0.0625 lb ai/acre). The two treatments applied as needed on August 10, 2000, against economic threshold populations of soybean looper included thiodicarb (0.45 lb ai/acre) and methoxyfenozide (0.125 lb ai/acre). Nontreated control plots also were included in study I. Four treatments were evaluated during study II and all insecticides were applied preventively. Those treatments included methoxyfenozide (0.0625 lb ai/acre, 2 F), diflubenzuron (0.0929 lb ai/acre), spinosad (0.0626 lb ai/acre) and a nontreated control. In both years, seed yields were determined by harvesting two rows per plot with a Massey-Ferguson 8 combine and correcting to 13% moisture.

Baton Rouge Study. In 1999, plots were 50 feet long by 10 rows (30-inch row spacing) and arranged in a randomized block design with four replications. Four treatments were evaluated. Diflubenzuron (0.0313 lb ai/acre) was applied preventively to 'Hartz 7550RR' (maturity group VII) soybeans at R2 to R3 stage (August 13, 1999) planted June 15, 1999. Spinosad (0.0313 lb ai/acre) and *lambda*-cyhalothrin (0.015 lb ai/acre) were applied as needed on August 27, 1999, once populations of velvetbean caterpillar and/or soybean looper exceeded the economic threshold. Nontreated control plots also were included.

In 2000, plots were 55 feet long by 10 rows (30-inch row spacing) and arranged in a randomized block design with four replications. Five treatments were evaluated during this study. Diflubenzuron (0.0313 lb ai/acre) and methoxyfenozide (0.125 lb ai/acre) were applied to 'Hartz 7550RR' (maturity group VII) soybeans at R2 to R3 stage (August 12, 2000) planted June 13, 2000. Spinosad (0.0313 lb ai/acre) and *lambda*-cyhalothrin (0.015 lb ai/acre) were applied as needed on August 31, 2000, once populations exceeded the economic threshold. Nontreated control plots also were included. Seed yield in 1999 was determined by harvesting two rows per plot with an Almaco small plot combine and correcting to 13% moisture.

Arthropod sampling and economic thresholds. Post-treatment arthropod samples (25 sweeps/plot with a standard 15-inch diameter sweep net) were taken three days after preventive treatment (DAPT) and once each week until soybeans matured to the R7 growth stage. Densities of velvetbean caterpillars, soybean loopers, southern green stink bugs and brown stink bug species were recorded. Foliar insecticide treatments were applied as needed when the density of the pest species, averaged across all plots within each treatment, exceeded the economic threshold. The economic thresholds for each species recommended by the Louisiana Cooperative Extension Service were the basis for management decisions (soybean looper = 38 larvae of any size/25 sweeps; velvetbean caterpillar = 76 larvae of any size/25 sweeps; stink bugs = nine adults and nymphs/25 sweeps) (Baldwin et al. 1999).

Data analysis. Mean numbers of velvetbean caterpillar and stink bugs were compared among treatments to determine significant differences at each date sampled and over the entire growing season using the SAS MIXED procedure (Littell et al. 1996). For variables with a significant F value (alpha=0.05), means were separated using Tukey's studentized range test (Tukey) (SAS Institute 1998). Dates were handled as a repeated measures effect. Seed yield data were analyzed using the MIXED procedure.

Results and Discussion

Crowley. In 1999, there were significant differences in densities of velvetbean caterpillar among treatments [$F(1,3) = 47.34$, $P > 0.05$] (Figure 1a). At the time preventive treatments were applied July 14, velvetbean caterpillar were not present and did not appear until 21 days after preventive treatment (DAPT). Peak populations occurred 56 DAPT and were one-third the velvetbean caterpillar economic threshold in nontreated plots (Figure 1a). Plots treated with diflubenzuron had significantly fewer velvetbean caterpillar than nontreated plots on that date. Soybean looper populations were extremely small (fewer than three larvae/25 sweeps) in all plots on all sampling dates. Even when pooled, the combined popula-

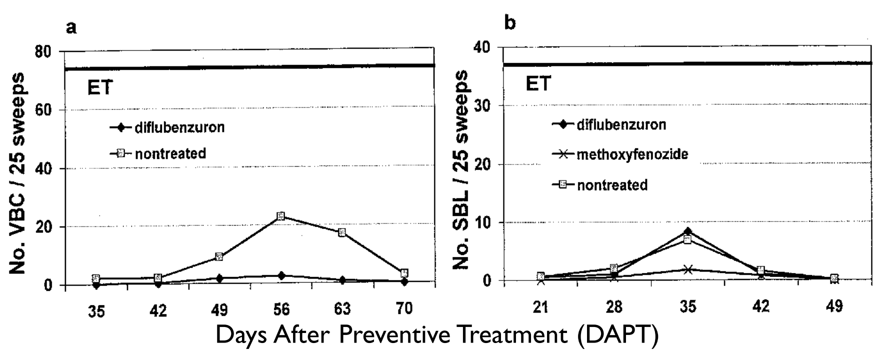

Figure 1. Weekly means of velvetbean caterpillar (VBC) and soybean looper (SBL) populations at Crowley, La., following preventive insecticide applications at the R2 to R3 growth stage on 15 July 1999 (a) and 6 July 2000 (b). ET = Economic Threshold.

tions of velvetbean caterpillar and soybean looper failed to reach the economic threshold. No treatments were applied for management of stink bugs because populations in all plots were below the economic threshold for all dates sampled. Yield data indicated no significant differences among treatments [F(1,3) = 1.20, P > 0.05] (Table 2).

Table 2. Effects of a preventive management strategy on soybean seed yield at Crowley, Southwest Louisiana.

		Seed yield (bu/acre)[1]	
Treatment[2]	Rate (lb ai/acre)	1999	2000
diflubenzuron	0.0313	42.4a	22.9a
methoxyfenozide	0.125	——	21.3a
nontreated	——	39.7a	22.6a

[1] Column means followed by the same letter do not differ significantly (P < 0.05; Tukey).
[2] All treatments were applied preventive.

In 2000, velvetbean caterpillar populations were negligible (fewer than four larvae/25 sweeps) in all plots on all sampling dates. Mean number of velvetbean caterpillars in nontreated plots on 28 (date of first appearance), 35, 42, 49, 56 and 63 DAPT were 0.1, 0.6, 0.9, 1.5, 1.0 and 0.1, respectively. Soybean looper populations were higher in 2000 than 1999, and there were significant differences among treatments [F(2,6) = 7.57, P < 0.05] (Figure 1b). Peak populations occurred 35 DAPT and were 18% of the soybean looper economic threshold in nontreated plots. Plots treated with methoxyfenozide had significantly fewer soybean loopers than diflubenzuron and nontreated plots on that date. Results from this study indicate methoxyfenozide may have the potential to control soybean looper for five weeks after application. No treatments were applied for stink bugs because populations in all plots were below the economic threshold for all dates sampled. Yield data indicated no significant differences among treatments [F(2,6) = 0.44, P > 0.05] (Table 2).

Insect pest densities were relatively low during both years at this location. Neither velvetbean caterpillar, soybean looper or the complex of stink bugs reached population levels requiring treatment. These studies demonstrated the unpredictability and monetary risk that may be incurred when a crop protection product is applied in a preventive manner, at a specified growth stage and prior to knowledge of pest presence and abundance.

Winnsboro. In 1999, there were significant differences among treatments for the control of soybean looper [$F(3,12) = 14.14$, $P < 0.05$] (Figure 2a,b). At the time that preventive treatments were applied on August 3, 1999, soybean looper populations averaged one larvae/25 sweeps. Of the two insect growth regulators applied, methoxyfenozide was most effective in maintaining soybean looper populations below the economic threshold for all dates sampled; whereas, diflubenzuron was ineffective against soybean looper (Figure 2a). Peak populations occurred 35 DAPT and exceeded the soybean looper economic threshold by 57% and 47% in diflubenzuron and nontreated plots, respectively. On this date, plots treated with methoxyfenozide had significantly fewer soybean loopers than diflubenzuron and nontreated plots, and populations were well below the economic threshold. Thiodicarb was applied on 35 DAPT to those plots designated for as-needed treatments against populations above the threshold level (Figure 2b). The treatment was effective in reducing numbers of soybean looper. Although the soybean looper population appeared to be completing a generation and numbers were declining in nontreated plots on 42 DAPT, plots treated with methoxyfenozide and thiodicarb were lower than diflubenzuron-treated plots for 14 days after the as-needed insecticide application. Velvetbean caterpillar populations remained very low with 15.4 as the highest mean number of larvae per 25 sweeps in the nontreated plots at 56 DAPT. Stink bug populations exceeded the economic threshold on 56 DAPT, and all plots were treated with *lambda*-cyhalothrin (0.025 lb ai/acre) (Figure 2c). There were no significant treatment effects on stink bug control for the study before the *lambda*-cyhalothrin treatment on 56 DAPT. Yield data indicated no significant differences among treatments [$F(3,12) = 1.60$, $P > 0.05$] (Table 3).

Table 3. Effects of management strategies on soybean seed yield at Winnsboro, Northeast Louisiana, 1999 and Study I of 2000.

Treatment [2]	Rate (lb ai/acre)	Seed yield (bu/acre) [1] 1999	2000
diflubenzuron	0.0313	20.1a	——
diflubenzuron	0.0626	——	12.6a
methoxyfenozide	0.125	20.6a	14.7a
methoxyfenozide	0.0625	——	14.9a
methoxyfenozide[3]	0.125	——	14.8a
thiodicarb[3]	0.45	24.2a	15.2a
nontreated	——	19.7a	13.1a

[1] Column means followed by the same letter do not differ significantly ($P < 0.05$; Tukey).
[2] Treatments not footnoted were applied preventive.
[3] Applied as-needed at economic threshold populations of soybean looper.

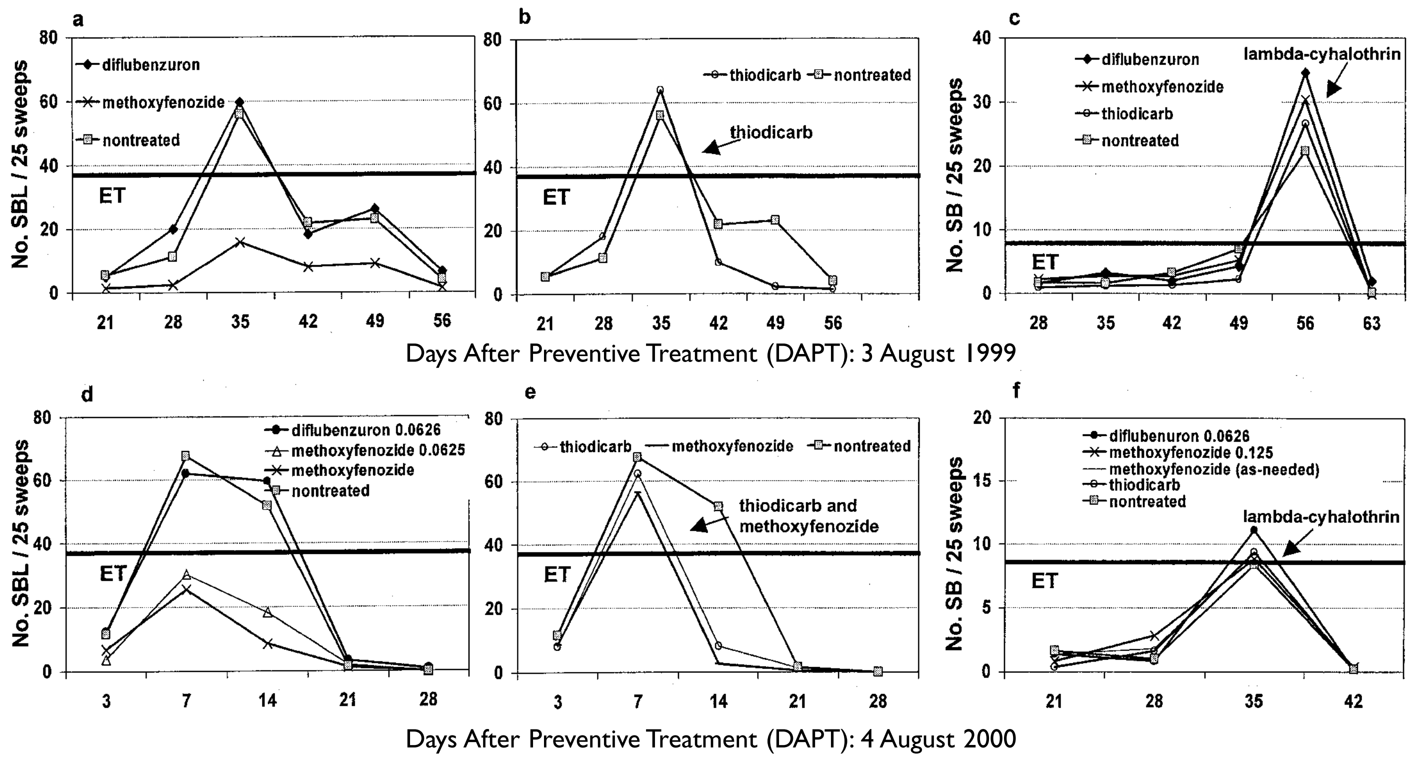

Figure 2. Weekly means of soybean looper (SBL), and southern green and brown stink bug (SB) populations at Winnsboro, La., following preventive insecticide applications at the R2 to R3 growth stage in 1999 (a,b,c) and 2000 (d,e,f). Thiodicarb was applied as-needed in both years, and methoxyfenozide only in 2000. ET = Economic Threshold.

In Study I of 2000, there were significant differences among treatments for the control of soybean looper [$F(5,20) = 10.69, P < 0.05$] (Figure 2d,e). At the time preventive treatments were applied on 4 August, soybean looper populations averaged less than 10 larvae in 25 sweeps across all plots. Similar to 1999, preventive applications of methoxyfenozide effectively maintained soybean loopers below the economic threshold for all dates sampled, while diflubenzuron was ineffective (Figure 2d).

Diflubenzuron was applied during this year at the rate labeled for soybean looper suppression (0.0626 lb ai/acre). Populations began to increase 7 DAPT and exceeded the soybean looper economic threshold by 63% and 78% for diflubenzuron and nontreated plots, respectively. The as-needed treatments of thiodicarb and methoxyfenozide were applied after plots were sampled on 7 DAPT (Figure 2e). Both treatments effectively reduced soybean looper populations below those in nontreated plots. Velvetbean caterpillar populations were negligible, with two larvae as the largest number collected in 25 sweeps for the entire study period. Stink bug populations exceeded the economic threshold on 35 DAPT, and all plots were treated with *lambda*-cyhalothrin (0.025 lb ai/acre) (Figure 2f). There were no significant treatment effects on stink bug control for the study, before the *lambda*-cyhalothrin treatment on 35 DAPT [$F(5,20 = 0.42, P > 0.05$]. Yield data indicated no significant differences among treatments [$F(5,20) = 1.33, P > 0.05$] (Table 3).

In Study II of 2000, there were significant differences among treatments (all applied in a preventive manner) for the control of soybean looper [$F(3,12) = 76.25, P < 0.05$] (Figure 3a). At the time treatments were applied on 4 August 2000, soybean looper populations averaged 10 larvae/25 sweeps. Populations increased 7 DAPT and exceeded the soybean looper economic threshold by 35% and 53% for diflubenzuron (0.0939 lb ai/acre) and nontreated plots, respectively (Figure 3a). Numbers of soybean loopers in plots treated with methoxyfenozide and spinosad were below the economic threshold. Spinosad, a recently registered compound that is effective against a broad spectrum of lepidopterans (Fitzpatrick et al. 2000a), was applied to compare residual control of diflubenzuron and methoxyfenozide with another insecticide recommended for control of the pest.

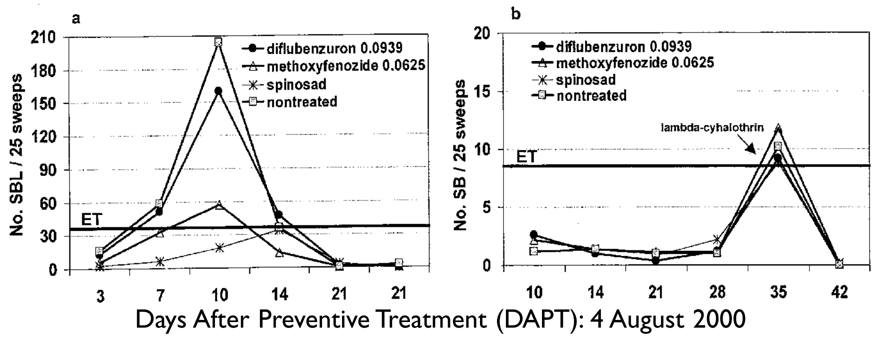

Figure 3. Weekly means of soybean looper (SBL) (a), and southern green and brown stink bug (SB) (b) populations at Winnsboro, La., study II. All treatments were applied at the R2 to R3 growth stage. ET = Economic Threshold.

At 10 DAPT in the diflubenzuron and nontreated plots, soybean looper populations exceeded the economic threshold by 322% and 437%, respectively. Additionally, numbers of soybean looper almost doubled from the previous sampling date in plots treated with spinosad and methoxyfenozide. High soybean looper populations in the methoxyfenozide and spinosad plots resulted from an oviposition event. Neonate and first instar larvae comprised the majority of the insects sampled on that date. Larval mortality is not immediate upon ingestion of spinosad and methoxyfenozide. In the case of spinosad, intoxicated insects may remain on the plant for one to two days (Anonymous 1996); whereas, methoxyfenozide-treated larvae stop feeding within 4 to 16 h after ingestion, prematurely slip their head capsule and eventually starve to death (Trisyono and Chippendale 1997, Dhadialla et al. 1998). This study indicated larval mortality from methoxyfenozide intoxication may occur slower relative to spinosad.

On 14 DAPT, soybean looper populations dramatically declined. Larval numbers in diflubenzuron plots exceeded the economic threshold by 24%, while those in nontreated plots were 94% of the economic threshold. Although soybean looper in plots treated with spinosad were below the economic threshold on 14 DAPT, populations were increasing, whereas, numbers of larvae in methoxyfenozide-treated plots were declining. Methoxyfenozide provided longer residual efficacy on soybean relative to spinosad when subjected to the hot, dry conditions during 2000. Soybean looper populations completed the generation by 21 DAPT, as the number sampled in nontreated plots was 0.4 larvae per 25 sweeps. Stink bug populations exceeded the economic threshold on 35 DAPT, and all plots were treated with *lambda*-cyhalothrin (0.025 lb ai/acre) (Figure 3b). There were no treatment effects for the control of stink bugs before treatment on 35 DAPT [$F(3,12) = 0.83, P > 0.05$]. Seed yield data indicated no significant differences among all preventive treatments and the nontreated control [$(3,12) = 1.67, P > 0.05$] (Table 4).

Table 4. Effects of a preventive management strategy on soybean seed yield at Winnsboro, Northeast Louisiana, Study II, 2000.

Treatment	Rate (lb ai/acre)	Seed yield (bu/acre) [1]
diflubenzuron	0.0939	13.3a
methoxyfenozide	0.0625	15.6a
spinosad	0.062	14.6a
nontreated	——	12.5a

[1] Column means followed by the same letter do not differ significantly ($P < 0.05$; Tukey).

Insecticide efficacy data at the Winnsboro location indicated methoxyfenozide, applied in a preventive manner or as needed, offers soybean looper control comparable to recommended insecticides, whereas, diflubenzuron, applied even in excess of the labeled rate (0.0939 lb ai/acre), was ineffective. Although plots were furrow irrigated, lack of yield loss in diflubenzuron and nontreated plots may have been a result of the hot, dry conditions in 1999 and 2000. Lambert and Heatherly (1991) demonstrated that decreased larval weight and an extended larval developmental period in soybean looper could be attributed to soybean plants stressed by either water deprivation or increased leaf temperatures resulting from reduced plant water. In subsequent studies, it was confirmed that when drought conditions persist, insecticide costs may not be recovered by preventing insect damage or by higher yields (Lambert and Heatherly 1995).

Baton Rouge. In 1999, there were significant differences among treatments in densities of velvetbean caterpillar [$F(3,9) = 2.54$, $P < 0.05$] (Figure 4a,b). At the time preventive treatments were applied August 13, 1999, velvetbean caterpillar populations did not exceed four larvae in 25 sweeps. Peak populations occurred 14 DAPT and were 61% of the velvetbean caterpillar economic threshold in nontreated plots. *Lambda*-cyhalothrin and spinosad were applied on 14 DAPT to plots designated for as-needed treatment (Figure 4b). Both insecticides reduced velvetbean caterpillar populations; however, populations appeared to be completing a generation and numbers were declining in nontreated plots on 21 DAPT. Soybean looper populations remained low (fewer than 8.3 larvae/25 sweeps) for all plots on all sampling dates, and no significant treatment effects were demonstrated [$F(3,9) = 2.54$, $P > 0.05$] (Figure 4d,e).

Numbers of soybean looper and velvetbean caterpillar larvae were pooled in determining whether treatment action was necessary on 14 DAPT (Figure 4f). Stink bug populations exceeded economic threshold, and all plots were treated with *lambda*-cyhalothrin (0.025 lb ai/acre) on 42 DAPT (Figure 5a,b). There were no differences among treatments in the control of stink bugs before the *lambda*-cyhalothrin treatment on 42 DAPT [$F(3,9) = 1.68$, $P > 0.05$]. Yield data indicated plots receiving insecticide treatments of diflubenzuron, *lambda*-cyhalothrin and spinosad had significantly higher yields than nontreated plots [$F(3,9) = 17.06$, $P < 0.05$] (Table 5). Higher yields in those plots appeared to result from the control of damaging insect populations, and there were no differences between a preventive management and IPM strategy.

Table 5. Effects of management strategies on soybean seed yield at Baton Rouge, Louisiana, 1999.

Treatment [1]	Rate (lb ai/acre)	Seed yield (bu/acre) [2]
diflubenzuron	0.0313	53.3a
nontreated	——	41.3b
spinosad [3]	0.031	51.1a
lambda-cyhalothrin [3]	0.015	54.1a

[1] Treatments not footnoted were applied preventive.
[2] Column means followed by the same letter do not differ significantly ($P < 0.05$; Tukey).
[3] Treatments applied as-needed for velvetbean caterpillar and soybean looper.

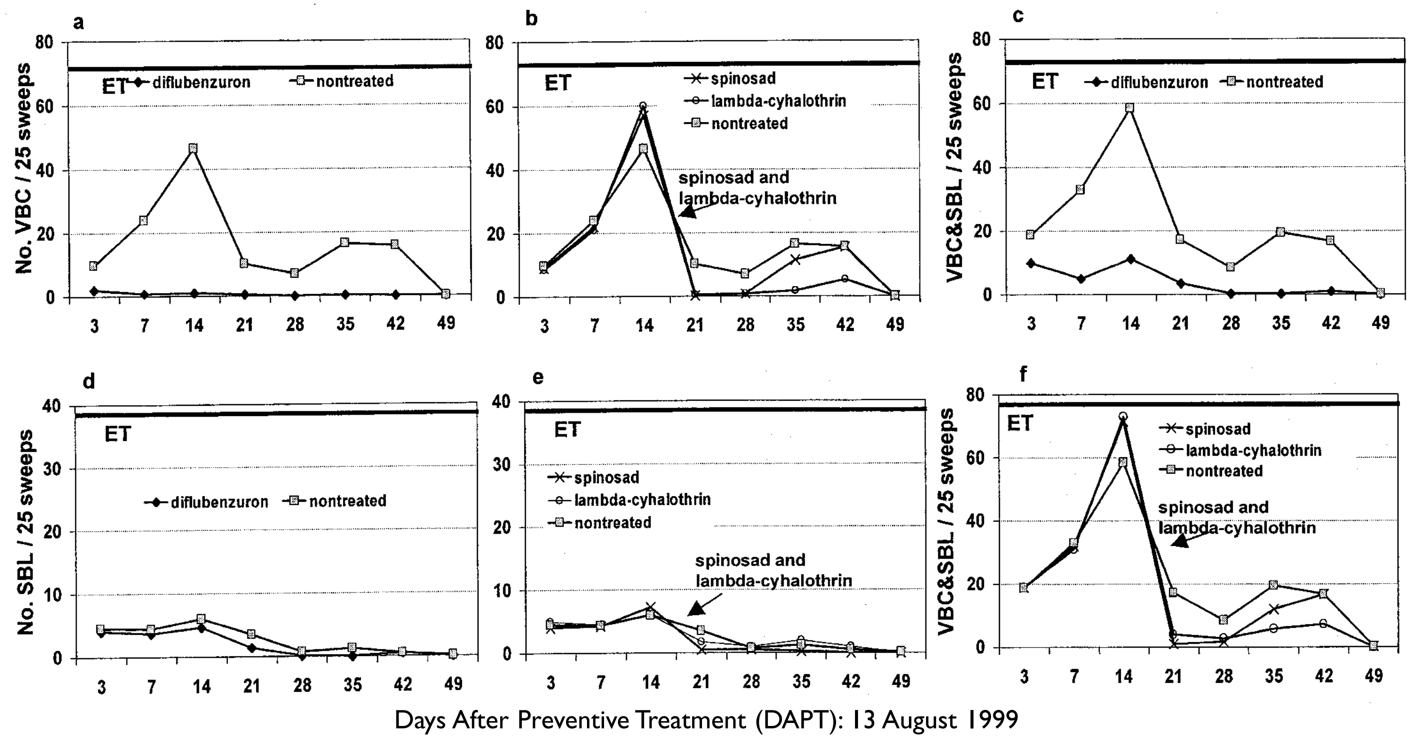

Figure 4. Weekly means of velvetbean caterpillar (VBC) (a,b) and soybean looper (SBL) (d,e) populations at Baton Rouge, La., following preventive insecticide applications at the R2 to R3 growth stage in 1999. The economic threshold was reached when the VBC and SBL populations were combined (c,f) [ET = No. VBC + 2(No. SBL) > 76]. Spinosad and *lambda*-cyhalothrin were applied as-needed.

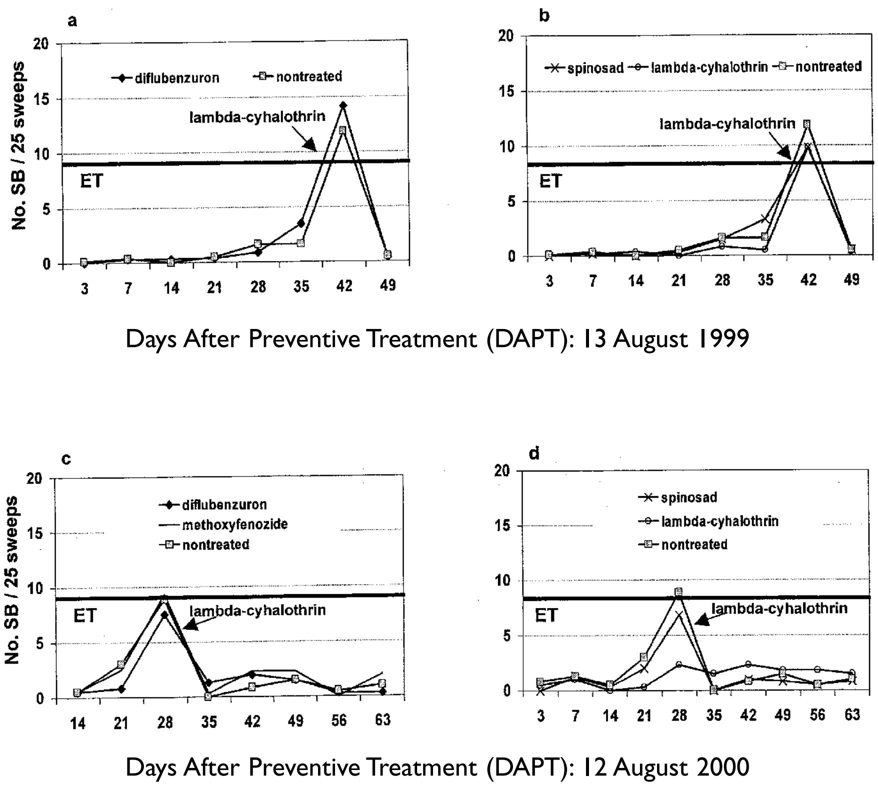

Figure 5. Weekly means of southern green and brown stink bug (SB) populations at Baton Rouge, La., following preventive insecticide applications at the R2 to R3 growth stage in 1999 (a,b) and 2000 (c,d). *Lambda*-cyhalothrin was applied for economic threshold populations of stink bugs in both years; however, in 2000, *lambda*-cyhalothrin was not applied to those plots previously treated with *lambda*-cyhalothrin for velvetbean caterpillar. ET = Economic Threshold.

In 2000, soybean looper populations were smaller than in 1999; velvetbean caterpillar populations were larger in 2000 than in 1999. Plots treated with diflubenzuron and methoxyfenozide had significantly fewer velvetbean caterpillars than all other plots for all dates sampled [$F(4,12) = 62.95$, $P < 0.05$], with means not exceeding 3.8 and 0.3 larvae/25 sweeps, for those respective treatments (Figure 6a). At the time preventive treatments were applied on August 12, 2000, velvetbean caterpillar popula-

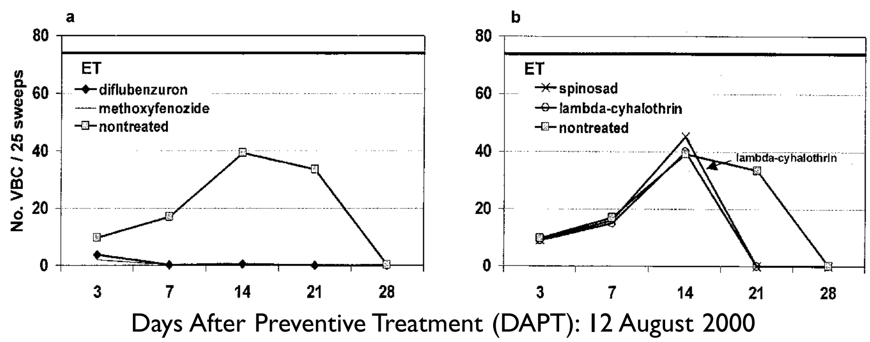

Figure 6. Weekly means of velvetbean caterpillar (VBC) populations at Baton Rouge, La., following preventive insecticide applications at the R2 to R3 growth stage on 12 August 2000. Diflubenzuron and methoxyfenozide were applied preventive (a), and spinosad and *lambda*-cyhalothrin were applied as-needed (b). Plots designated for as-needed treatment were estimated to be at least 20% defoliation, which is a level justifying treatment.

tions did not exceed an average of 10 larvae in 25 sweeps for all plots. Peak populations occurred 14 DAPT and were 61% of the velvetbean caterpillar economic threshold in nontreated plots. Combined numbers of soybean looper and velvetbean caterpillar did not exceed a level requiring treatment. Soybean plants were in the R2 to R3 growth stage, however, and defoliation was estimated to be higher than 20%.

During bloom and pod set, defoliation of soybeans should not exceed 20% to 25% if yield loss is to be avoided (Baldwin et al. 1999, Layton and Boethel 1988). As-needed insecticide treatments, *lambda*-cyhalothrin and spinosad, were applied on 14 DAPT and effectively reduced velvetbean caterpillar populations (Figure 6b). The velvetbean caterpillar population remained at 44% of the economic threshold in nontreated plots on 21 DAPT.

There were significant differences among treatments for the control of stink bugs [$F(4,12) = 2.57$, $P < 0.05$]. Stink bug populations reached or exceeded economic threshold on 28 DAPT in all plots, except those previously treated with *lambda*-cyhalothin for velvetbean caterpillar (Figure 5c,d). Numbers of stink bugs in plots treated with *lambda*-cyhalothrin were lower than those in nontreated plots on that date and did not reach a level requiring treatment for the remainder of the season (Figure 5d). The brown stink bug was the only species in the samples taken in those plots on 28 DAPT. Residual control with *lambda*-cyhalothrin against late-season soybean pests is not completely known; however, deposition of stink bug egg masses may have coincided with treatment for velvetbean caterpillar, subsequently removing potential damaging populations of stink bugs. *Lambda*-cyhalothrin (0.025 lb ai/acre) was applied to all other plots following sampling on 28 DAPT and effectively reduced stink bug populations (Figure 5c,d). Using *lambda*-cyhalothrin instead of diflubenzuron for velvetbean caterpillar control also may provide control of southern green stink bugs.

Studies conducted during 1999 and 2000 at three Louisiana locations have demonstrated that diflubenzuron and methoxyfenozide, because of their residual activity, are effective as preventive management strategies of late-season lepidopteran soybean insect pests. Methoxyfenozide has proved to be effective against soybean looper and velvetbean caterpillar and may have applicability statewide, whereas diflubenzuron is effective only against the latter and may be limited to use in the southern production regions where velvetbean caterpillars historically cause damage. Diflubenzuron applied against velvetbean caterpillar, and methoxyfenozide, against both lepidopterans, demonstrated control comparable to insecticides that are applied when pest species reach or exceed economic thresholds.

Thiodicarb and methoxyfenozide, evaluated for soybean looper, and *lambda*-cyhalothrin and spinosad, evaluated for velvetbean caterpillar, were effective in reducing larval numbers of those insect species when applied as needed. Additionally, while residual efficacy of diflubenzuron has been well documented, the activity of methoxyfenozide, at both rates and formulations, to perform similarly was not known. Even if methoxyfenozide is applied when a pest species reaches its economic threshold, it should provide the activity to protect soybeans if multiple generations of velvetbean caterpillar and soybean looper appear. Spinosad, applied at 0.062 lb ai/acre, also demonstrated residual activity against soybean looper; however, it appeared to have shorter residual relative to methoxyfenozide. This insecticide was applied preventive in only one study; therefore, additional research is needed to substantiate these findings.

Neither IGR demonstrated control or suppression of the soybean stink bug complex, a claim often made by growers who use diflubenzuron (Smith 1999); therefore, other treatments are still needed for damaging levels of stink bugs. This fact has little implication for cotton-soybean agroecosystems of northern Louisiana where soybean looper must be considered. Insecticides recommended in Louisiana for stink bug control are ineffective against soybean looper (Table 6); therefore, regardless of management approach, preventive or as-needed, two insecticides are necessary. In southern Louisiana, if damaging populations of velvetbean caterpillars and southern green stink bugs occur simultaneously or in a narrow temporal window, a preventive management approach may be an unnecessary production input if a class of insecticide recommended for control against both insects is used. Those classes include organophosphates and pyrethroids. This occurred at the Baton Rouge location in 2000; whereas, in the studies conducted at the Winnsboro location in 1999 and 2000, economic threshold populations of soybean looper and stink bugs were separated by three and four weeks, respectively. The inability to predict the occurrence of late-season soybean insect pests is a limitation of a preventive management strategy because insecticide applications are based on crop growth stage rather than pest presence.

Brown stink bug, *Euschistus servus*, is one of several species of stink bugs commonly found in Louisiana soybean.

Table 6. Insecticides recommended by the Louisiana Cooperative Extension Service for control of velvetbean caterpillar, soybean looper and stink bugs.

Insect	Insecticides Recommended	Rate (lb ai/acre)
Velvetbean Caterpillar	Sevin	0.25-0.5
	Lannate	0.125
	Methyl parathion	0.25
	Bacillus thuringiensis	(See Label)
	Ambush	0.05-0.1
	Pounce	0.05-0.1
	Larvin	0.25-0.4
	Karate	0.015-0.025
	Lorsban	0.5
	Tracer	0.031-0.062
Soybean Looper	*Bacillus thuringiensis*	(See Label)
	Larvin	0.45-0.75
	Tracer	0.031-0.062
Stink Bugs		
Green / Southern Green	Methyl parathion	0.25-0.5
	Orthene	0.75
	Scout Xtra	0.016-0.024
	Karate Z	0.025-0.03
Brown	Methyl parathion	0.5
	Orthene	0.75

Soybean Maturity Groups and Preventive Management

Objective

To determine the occurrence of velvetbean caterpillar in different soybean maturity groups commonly grown in Louisiana, and under what circumstances a preventive management program that uses diflubenzuron be considered for insect management.

Materials and Methods

Location. A field trial was conducted during the summer of 2000 at the Central Research Station, Ben Hur Farm, located three miles south of Baton Rouge (East Baton Rouge Parish).

Field study. Plots were 55 feet by 20 rows (30-inch row spacing) and arranged in a randomized complete block design with a 3 X 4 factorial treatment arrangement in four replications. Soybean varieties tested represented the four maturity groups recommended for Louisiana: 'Hartz 4998RR' (maturity group IV), planted April 18, 2000; 'Asgrow 5901RR' (maturity group V), planted May 5, 2000; 'Asgrow 6101RR' (maturity group VI), planted June 13, 2000; and 'Hartz 7550RR' (maturity group VII), planted June 13, 2000. Insecticides tested on the four maturity groups included diflubenzuron (0.0313 lb ai/acre), applied at the R2 to R3 growth stage; *lambda*-cyhalothrin (0.015 lb ai/acre), applied when populations of velvetbean caterpillar reached the economic threshold; and a nontreated control. Treatments were applied with a John Deere 6000 High Cycle calibrated to deliver 14.0 GPA through TeeJet 8002VS flat fan nozzles (two/row). Because of low larval populations, only diflubenzuron-treated and nontreated plots were evaluated within maturity groups IV and V. Percent defoliation was determined for maturity group VI and VII soybeans by harvesting one row-meter per plot at five days after the as-needed treatment. The surface area of soybean leaflets in diflubenzuron, *lambda*-cyhalothrin and nontreated plots was recorded using a leaf area meter (Model LI-3000, Li-Cor, Lincoln, Neb.). Defoliation in *lambda*-cyhalothrin and non-treated plots was estimated as a percentage of the leaf area present in diflubenzuron-treated plots.

Arthropod sampling and economic thresholds. Post-treatment arthropod samples (25 sweeps/plot with a standard 15-inch diameter sweep net) were taken three days after preventive treatment (DAPT) and once each week until soybeans matured to the R7 growth stage. Densities of velvetbean caterpillar, southern green stink bug and brown stink bug species were recorded. Foliar insecticide treatments were applied as needed when the density of the pest species, averaged across all plots within each treatment, exceeded the economic threshold. The economic thresholds for each species recommended by the Louisiana Cooperative Extension Service were the basis for management decisions (velvetbean caterpillar = 76 larvae of any size/25 sweeps; stink bugs = nine adults and nymphs/25 sweeps) (Baldwin et al. 2000).

Data analysis. Mean numbers of velvetbean caterpillar and stink bugs were compared among treatments to determine significant differences at each date sampled and over the entire growing season using the SAS MIXED procedure (Littell et al. 1996). For effects with a significant *F* value (alpha=0.05), means were separated using Tukey's studentized range test (Tukey) (SAS Institute 1998). Dates were handled as a repeated measures effect. Yield data also were analyzed using the MIXED procedure.

Soybean varieties representing maturity groups IV, V, VI and VII, which are commonly grown in Louisiana.

Results and Discussion

Densities of velvetbean caterpillar present among the four maturity groups studied were significantly different [$F(3,39.8) = 95.91$, $P < 0.05$](Figure 7a). Late maturing group VI and VII soybeans were most susceptible to infestation by velvetbean caterpillar, and early maturing group IV and V soybeans were least susceptible. Populations were not present or remained very low in nontreated plots for all maturity groups until 30 July (week 8), at which time densities of larvae were approximately 17% of the velvetbean caterpillar economic threshold in nontreated plots in maturity group VI soybeans.

In the maturity group IV soybeans, mean number of velvetbean caterpillars sampled did not exceed one larva/25 sweeps in either diflubenzuron-treated or nontreated plots for all dates sampled. On July 30, when significant numbers appeared, these soybeans were in the R7 growth stage (physiological maturity) and no longer suitable as hosts for velvetbean caterpillar. Populations were higher in maturity group V soybeans than in the group IVs, although numbers remained small [$t(210) = 3.81$, $P < 0.05$]. Densities peaked on August 20 (week 11) to only 16.4% of the economic threshold in nontreated plots of maturity group V soybeans (R6 growth stage). In this study, a preventive management strategy for velvetbean caterpillar was unnecessary for maturity group IV and V soybeans. These results are consistent with McPherson et al. (1996), in which early maturing group IV and V varieties had the lowest mean infestations of velvetbean caterpillar when compared to later maturing group VI, VII and VIII soybeans. Similarly, Boyd et al. (1997) determined velvetbean caterpillar occurred in higher numbers in maturity group V soybeans compared to maturity group IV, although populations failed to reach a level requiring treatment in either maturity group.

Velvetbean caterpillars were more abundant in maturity group VI and VII soybeans. Although maturity group V soybeans had not reached physiological maturity in late July when populations were increasing, they were less attractive as a host compared to the maturity group VI and VII soybeans. These later maturing soybeans were in beginning to full bloom (R1 to R2 growth stages) and late vegetative to beginning bloom growth stages (V10 to R1 growth stages), respectively, on July 30 (week 8). Populations remained at sub-threshold levels in maturity group VI and VII soybeans for all sampling dates, with numbers fluctuating from late July through mid-September. Numbers of velvetbean caterpillar peaked in maturity group VI soybean on 3, 21 and 42 DAPT (weeks 9, 12 and 15)

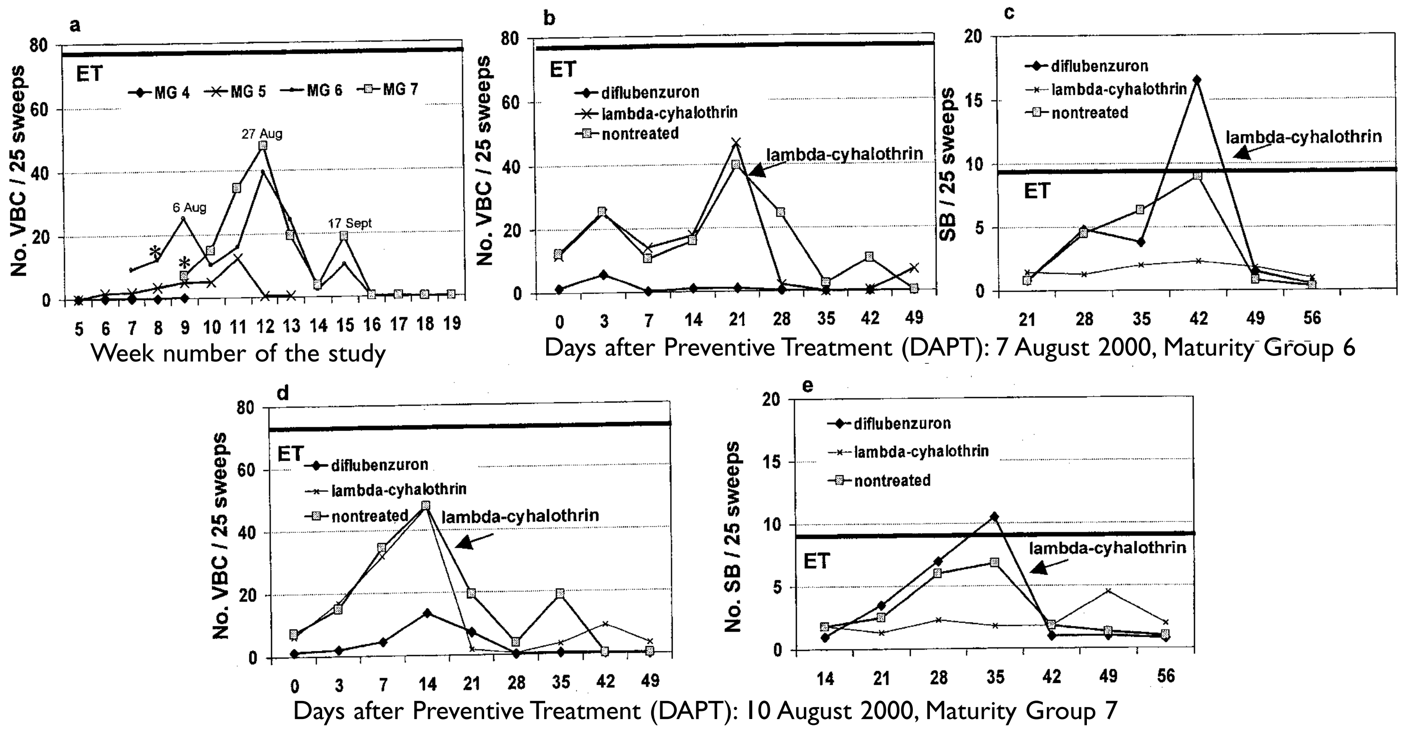

Figure 7. Weekly means of velvetbean caterpillar (VBC) (a,b,d) and southern green and brown stink bugs (SB) (c,e) populations at Baton Rouge, La., following preventive applications of diflubenzuron at the R2 to R3 growth stage in 2000. Defoliation exceeded 20% and *lambda*-cyhalothrin was applied as-needed for VBC. *Lambda*-cyhalothrin also was applied to nontreated and diflubenzuron-treated plots for stink bugs. ET = Economic Threshold, *=R2-R3 growth stage.

and were 33%, 52% and 14% of the economic threshold in nontreated plots, respectively (Figure 7b). Plots treated with diflubenzuron had significantly fewer larvae than nontreated plots on each of those dates [week 9: $t(403) = 8.46$, $P < 0.05$; week 12: $t(403) = 22.38$, $P < 0.05$; week 15: $t(403) = 4.45$, $P < 0.05$]. In maturity group VII soybeans, numbers peaked on 14 and 35 DAPT (week 12 and 15) and were 63% and 25% of the economic threshold in nontreated plots, respectively (Figure 7d). Diflubenzuron-treated plots also had significantly fewer larvae on each of those dates relative to nontreated plots [week 12: $t(403) = 18.87$, $P < 0.05$; week 15: $t(403) = 8.35$, $P < 0.05$]. On week 12, when populations were highest in maturity group VI and VII soybeans, defoliation exceeded 20% in nontreated plots and required treatment based on action levels during bloom and pod set of soybeans (Baldwin et al. 2000). *Lambda*-cyhalothrin was applied to those plots designated for as-needed treatments in maturity group VI and VII soybeans on 21 and 14 DAPT, respectively (week 12) (Figure 7b,d). This insecticide has demonstrated excellent activity against velvetbean caterpillar in Louisiana and is one of several products recommended for their control (Fitzpatrick et al. 2000b)(Table 6).

Lambda-cyhalothrin, applied as needed, was effective in reducing velvetbean caterpillar populations below those in the nontreated plots. On 28 and 21 DAPT in maturity group VI and VII soybeans, respectively, plots treated with *lambda*-cyhalothrin had significantly fewer velvetbean caterpillars than nontreated plots. Defoliation was quantified five days after the as-needed treatment. Leaf area measurements were taken on this specific date because larval mortality with *lambda*-cyhalothrin occurs rapidly (within a few hours), and defoliation in those plots would have initially ceased on the day of treatment. Therefore, the amount of foliage loss present on the day of treatment and five days later, if treatment action was not taken, would be known. Because of highly effective velvetbean caterpillar control, diflubenzuron-treated plots suffered little to no damage; therefore, defoliation in *lambda*-cyhalothrin-treated and nontreated plots was determined as a percentage of the leaf area present in diflubenzuron-treated plots. The decision to treat with *lambda*-cyhalothrin on week 12 in maturity group VI and VII soybeans was accurate because the level of defoliation in those plots treated as needed exceeded the 20% defoliation threshold (Table 7). If control measures had not been initiated, velvetbean caterpillar likely would have caused at least an additional 6% and 7% damage in maturity group VI and VII soybeans, respectively.

Table 7. Percent defoliation of *lambda*-cyhalothrin-treated and nontreated plots in maturity group VI and VII soybeans by velvetbean caterpillar.

Treatment	Maturity Group	Leaf Area (cm^2)	% Defoliation[1]
diflubenzuron		32460.2	——
lambda-cyhalothrin[2]	VI	22668.4	30.2
nontreated[3]		20934.0	35.5
diflubenzuron		35431.0	——
lambda-cyhalothrin	VII	28102.4	20.7
nontreated		25861.6	27.0

[1] Defoliation expressed as a percentage of the foliage present in diflubenzuron-treated plots.
[2] *Lambda*-cyhalothrin-treated plots are estimates of defoliation on the day of treatment.
[3] Nontreated plots are estimates of defoliation if treatment action not taken in five days.

During 2000, velvetbean caterpillar completed two to three generations, with populations peaking on three separate weeks in maturity VI and VII soybeans. Populations of first and second generation velvetbean caterpillars that appear during July in Louisiana are not generally heavy enough to warrant control measures; however, the third generation, occurring in late August and early September, often builds to tremendous populations (Dugas and Gray 1943). This sequence of events did not take place during our study. Early generations did contribute to the overall damage sustained by maturity group VI and VII soybeans. Those populations occurring at sub-threshold levels for consecutive weeks, but defoliating at an economic threshold level, justified insecticide treatment on week 12.

Stink bugs (primarily southern green stink bugs) occurred in damaging populations and required treatment in maturity group V, VI and VII soybeans. Densities of stink bugs did not exceed one per 25 sweeps for any sampling date in maturity group IV soybeans; therefore, treatment action was not justified. Previous studies conducted in Louisiana have indicated maturity group IV soybeans planted in April were more heavily infested by stink bugs than were maturity group V soybeans (Boyd et al. 1997, Baur et al. 2000). In each of the studies, southern green stink bug was the dominant species. Unusually low numbers of stink bugs during this study may have been because of adjacently planted field peas, *Phaseolus* spp. L., and corn, *Zea mays* L., that also are suitable hosts for this polyphagous insect. These crops flowered earlier than the group IV soybeans; therefore, stink bug populations were concentrated and subsequently removed when insecticide treatments were applied to the field beans and corn. Field beans are attractive to stink bugs, and planting small blocks of this crop is recommended by the Louisiana Cooperative Extension Service as an effective approach for trapping stink bugs (Baldwin et al. 2000). In maturity group V soybeans, stink bug populations did exceed the economic threshold, and *lambda*-cyhalothrin (0.025 lb ai/acre) was applied to diflubenzuron and nontreated plots.

In maturity group VI and VII soybeans, stink bug populations peaked on 42 and 35 DAPT in maturity group VI and VII soybeans, respectively, and *lambda*-cyhalothrin was applied to diflubenzuron and nontreated plots (Figure 7c,e). *Lambda*-cyhalothrin effectively reduced stink bug populations in those plots that required treatment. Stink bugs in group VI and VII soybeans previously treated with *lambda*-cyhalothrin for velvetbean caterpillar did not exceed the economic threshold; therefore, treatment was not required. Residual control with *lambda*-cyhalothrin is not completely known; however, deposition of stink bug egg masses may have coincided with treatment for velvetbean caterpillar, subsequently removing potential damaging populations. In recent studies, *lambda*-cyhalothrin applied at 0.018 and 0.023 lb ai/acre against southern green stink bug and velvetbean caterpillar, respectively, has significantly reduced populations compared to nontreated plots for 14 days after treatment (Crowe et al. 2000, Taylor and McPherson 2000). Results from this study confirm *lambda*-cyhalothrin's activity against velvetbean caterpillar and stink bugs, when the southern green stink is the most common species. In contrast, diflubenzuron had no effect on stink bug populations in this study.

Overall seed yields among diflubenzuron-treated, *lambda*-cyhalothrin-treated and nontreated plots were not significantly different [$F(2,35) = 2.91$, $P > 0.05$] (Table 8). There was not a significant insecticide by maturity group interaction [$F(4,35) = 1.08$, $P > 0.05$], but the trend appeared to be for plots treated with diflubenzuron, regardless of level of insect damage incurred within a maturity group, to yield higher than *lambda*-cyhalothrin and nontreated plots. This phenomenon has appeared in other research involving diflubenzuron. No statistical differences exist, but diflubenzuron-treated plots yielded higher than nontreated plots (Way

Table 8. Effects of soybean maturity groups and management strategies on yield, Baton Rouge, Louisiana, 2000.

Insecticide[1]	Maturity Group	Seed yield (bu / acre)[2] Insecticide	Seed yield (bu / acre)[2] Insecticide X Maturity Group	Seed weight (g / 100 seed) Insecticide	Seed weight (g / 100 seed) Insecticide X Maturity Group
	IV		41.3a		15.5a
	V		49.8a		14.2a
diflubenzuron		49.1a		15.2a	
	VI		54.4a		16.0a
	VII		50.8		15.3a
	VI		45.8a		14.0a
lambda-cyhalothrin[3]		47.4a		13.6b	
	VII		48.9a		13.2a
	IV		41.0a		15.1a
	V		45.8a		13.5a
nontreated		44.6a		14.4b	
	VI		43.4a		14.6a
	VII		48.1a		14.7a

[1] Treatments not footnoted were applied preventive.
[2] Column means followed by the same letter do not differ significantly ($P < 0.05$; Tukey).
[3] Applied as-needed for velvetbean caterpillar.

et al. 1992; Boethel 1991; Funderburg et al. 1999). In maturity group VI and VII soybeans, where significant insect populations were present, numerically higher yields in diflubenzuron-treated plots were probably the result of control of velvetbean caterpillar densities that occurred in nontreated plots at a sub-threshold sampling level for a six-week period (weeks 9 through 15). It was the cumulative damage caused by velvetbean caterpillar over this period that was significant enough to exceed the defoliation economic threshold (Baldwin et al. 2000).

For soybean seed weight, there was not a significant insecticide by maturity group interaction [$F(4,30.4) = 1.07$; $P > 0.05$] (Table 8). Insecticide treatments did significantly influence soybean seed weight [$F(2,32.5) = 26.84$, $P < 0.05$]. Plots treated with diflubenzuron weighed significantly more than those in *lambda*-cyhalothrin-treated and nontreated plots. Russin et al. (1987) demonstrated that under low infestation levels of stink bugs on soybean, non-damaged seeds compensated for damaged seeds by increasing the weights of non-damaged seeds. Under conditions of extreme insect pressure, few non-damaged seeds would be available to compensate for the number of damaged seeds. Similarly, in this study, low velvetbean caterpillar and stink bug densities were present in diflubenzuron-treated plots; therefore, it is possible compensation by non-damaged seeds occurred. Results from this study indicated diflubenzuron may have an influence on soybean yield. Higher yields in diflubenzuron-treated plots may be more associated with increased individual seed weights rather than an increase in non-damaged seed number.

Results from this study indicate a diflubenzuron preventive management strategy may have optimal use in a late-maturing soybean, planted in southern Louisiana, and in an area that historically requires control measures for velvetbean caterpillar. Additionally, this program may be appealing to producers and scouts when soybeans are protected through velvetbean caterpillar populations that occur for consecutive weeks at a sub-threshold level, yet the cumulative damage of those populations equates to a defoliation economic threshold. An economic threshold based on numbers of insects per unit area is a preferred method for determining whether treatment action is necessary. In this study, however, velvetbean caterpillars failed to reach the economic threshold based on insect numbers, and the decision to treat was based upon percent defoliation.

Currently, there is no easy or practical way of visually estimating percent defoliation of whole plants in the field, and untrained persons have a tendency to overestimate damage (Kogan and Turnipseed 1980). While this problem would be avoided when a diflubenzuron preventive management strategy is used against velvetbean caterpillar, this study confirmed applying an insecticide as needed (IPM approach) when a defoliation threshold is accurately estimated also is an effective method for determining when control measures should be employed.

A preventive strategy, whereby an insecticide is applied before knowledge of pest presence, cannot be justified for an early soybean production system (early planted, maturity group IV), based upon velvetbean caterpillar population dynamics. Maturity group V soybeans avoided damaging populations of velvetbean caterpillar in this study, and a preventive strategy was unnecessary. If planting of this maturity group is delayed, however, insect pressure could be greater, and potentially preventive applications of diflubenzuron could be used with less risk of an unnecessary treatment.

Diflubenzuron and Boron for Yield Enhancement in Soybean

Objective

To determine the effect of diflubenzuron, in combination with boron, for yield enhancement in soybeans absent of insects.

Materials and Methods

Location. Field trials were conducted during the summers of 1999 and 2000 at the St. Gabriel Research Station, located 10 miles south of Baton Rouge, Louisiana (Iberville Parish). The soil at the site was a Sharkey clay.

1999 field experiment. Plots were 90 feet long by 24 rows (36-inch spacing) and arranged in a randomized complete block with a split plot design having four replications. Treatments were applied with a tractor-mounted sprayer and compressed air system calibrated to deliver 15.3 GPA through TeeJet 8002 flat fan nozzles (two/row) at 30 psi. Main plots were no overspray and overspray tank mixtures of thiodicarb (0.45 lb ai/acre) + tralomethrin (0.024 lb ai/acre) for control of all insects. Oversprays were applied at the R2 to R3 growth stage to 'Asgrow 6101RR' (maturity group VI) soybeans, planted May 22, 1999, with subsequent oversprays applied on 14, 21 and 28 days after the initial application. The following four subplot treatments were applied preventive at the R2 to R3 growth stage (July 21, 1999): diflubenzuron (0.0313 lb ai/acre), boron (0.2 lb ai/acre), a diflubenzuron + boron tank mixture (0.0313 + 0.2 lb ai/acre) and a nontreated control. Foliage from the upper one-third of the soybean canopy was collected from each plot not oversprayed on 14 DAPT, dried at 80 degrees C for 24 hours and analyzed by the LSU AgCenter Plant Analysis Laboratory for micro- and macronutrient concentrations using inductively coupled plasma (ICP) spectrometry (Huang and Schulte, 1985).

2000 field experiment. Plots were 84 feet long by 24 rows (36-inch spacing) and arranged in a randomized complete block with a split plot design having four replications. Treatment types, application rates and methods of applications were the same as those used in 1999. Oversprays were applied at the R2 to R3 growth stage to 'Asgrow 6101RR' (maturity group VI) soybeans, planted June 19, 2000, with subsequent oversprays applied on 14 and 28 days after the initial application. Subplot treatments were applied preventive at the R2 to R3 growth stage (16 August 2000). In both years, seed yield was determined by harvesting two rows per subplot with an Almaco small plot combine and correcting to 13% moisture. In 2000, seed weights were obtained by weighing a sample of 100 soybeans from each plot with weights standardized to 13% moisture.

Arthropod sampling and economic thresholds. Post-treatment arthropod samples (25 sweeps/plot with a standard 15-inch diameter sweep net) were taken three days after preventive treatment (DAPT) and once each week until the R7 growth stage. Densities of all major soybean arthropod pests including threecornered alfalfa hoppers, *Spissistilus festinus* (Say), banded cucumber beetles *Diabrotica balteata* LeConte, bean leaf beetles, *Cerotoma trifurcata* (Forster), velvetbean caterpillars, green cloverworms, *Plathypena scabra* (F.), soybean loopers, southern green stink bugs and brown stink bug species were recorded. Foliar insecticide treatments were applied as needed when the density of the pest species, averaged across all plots within each treatment, reached or exceeded the economic threshold. The economic thresholds for each species recommended by the Louisiana Cooperative Extension Service were the basis for management decisions (Baldwin et al. 1999).

Data analysis. Total seed yield, seed weight and boron content in leaf tissue were determined for each treatment. Means were compared among treatments using the SAS MIXED procedure (Littell et al. 1996). For variables with a significant F value (alpha=0.05), means were separated using Tukey's studentized range test (Tukey) (SAS Institute 1998).

Results and Discussion

Oversprays of thiodicarb + tralomethrin were applied on four dates in 1999 and three dates in 2000, and these applications were effective in creating an absence of insect pressure, although no pest species reached a level requiring treatment in non-oversprayed plots. In 1999, boron contents in leaf tissue ranged from 37.9 to 43.1 ppm, and there were significant differences among treatments [$F(3,9) = 5.68$, $P < 0.05$] (Table 9). Although the boron treatment was significantly greater than the nontreated control, soybeans within all treatments contained boron within the recommended range of 20 to 60 ppm for seed production (Plank 1989). Rehm (1999) demonstrated no response in soybean yield with applications of boron when the leaf concentration was 40 ppm; however, yields were reduced when leaf tissue concentration reached 63 ppm.

The interaction between overspraying (main plot) and the preventive treatment (subplot) on seed yield was not significant in 1999 [$F(3,26) = 0.83$, $P > 0.05$] or 2000 [$F(3,26) = 1.41$, $P > 0.05$]; therefore, diflubenzuron, applied alone or in combination with boron, did not enhance yields in the absence of significant insect pressure (Table 9). If soybean seed yields were enhanced, within the oversprayed main plots, diflubenzuron-treated subplots should have yielded higher than the nontreated subplots. In 2000, there also was not a significant overspraying (main plot) and preventive treatment (subplot) interaction for seed weight [$F(3,26) = 0.06$, $P > 0.05$] (Table 9).

In addition to boron, fungicides often have been applied with diflubenzuron in preventive applications at the R2 to R3 growth stage. Results from those studies have indicated yield enhancement may be related primarily to damaging levels of diseases or insects. Way et al. (1995) demonstrated no yield increase relative to the nontreated control following application of diflubenzuron; however, co-application of the fungicide benomyl with diflubenzuron yielded 14.3 bu/acre higher than the nontreated control. Densities of lepidoptera larvae were low while diseases (anthracnose, *Colletotrichum* spp. and *Glomerella* spp.) were prevalent and approaching severe ratings, leading to a conclusion that yield response was attributed to disease control. Boethel (1991) found no yield enhancement with diflubenzuron, applied alone or co-applied with benomyl, when plots were oversprayed for total insect control. Subthreshold populations of velvetbean caterpillar were present in plots that were not oversprayed, however, and those treated with diflubenzuron + benomyl yielded approximately 7.1 bu/acre more than non-oversprayed

Table 9. Effects of diflubenzuron and boron on soybean seed yield, seed weight and leaf boron content at St. Gabriel, South Louisiana, 1999 and 2000.

			Seed yield (bu/acre) [1]		Boron (ppm)	Seed weight (g/100)
	Treatment	Rate (lb ai/acre)	1999	2000	1999	2000
No overspray	diflubenzuron	0.0313	43.4a	44.1a	37.9b	17.5a
	boron	0.2	39.5a	40.3a	43.1a	17.3a
	diflubenzuron + boron	0.0313 0+ 0.2	40.3a	46.0a	41.8ab	17.5a
	nontreated	——	43.0a	43.4a	37.9b	17.4a
Overspray [2]	diflubenzuron	0.0313	49.2a	43.8a	——	17.4a
	boron	0.2	49.3a	44.4a	——	17.0a
	diflubenzuron + boron	0.0313 + 0.2	50.5a	44.4a	——	17.3a
	nontreated	——	50.0a	44.3a	——	17.1a

[1] Column means followed by the same letter do not differ significantly ($P < 0.05$; Tukey).
[2] Tank mixtures of thiodicarb (0.45 lb ai/acre) + tralomethrin (0.024 lb ai/acre) for control of all insects, applied at the R2 to R3 growth stage and on 14, 21 and 28 DAPT in 1999 and on 14 and 28 DAPT in 2000.

plots treated with benomyl. Additionally, Leonard (1991) also indicated no yield difference between diflubenzuron, applied alone and in combination with benomyl, at the R3 growth stage. Soybean looper infestations were a factor in the study, rather than disease. The failure of diflubenzuron to control soybean looper probably resulted in the poor yield response.

Soybeans grown in a soil of predominantly clay composition and in the absence of significant insect pressure did not respond to preventive applications of diflubenzuron, boron or the combination of both with enhanced yields in this study. Although yield responses have been correlated with seed weight, as demonstrated in a Georgia study (Gascho and McPherson 1997), our findings did not support that conclusion. Sandy soils, in which boron may be leached with rainfall and irrigation, have typically demonstrated the greatest responses to boron (Gascho and McPherson 1997). In the absence of significant insect pest densities, yield enhancement of soybean may be related primarily to deficiency of boron in soils. Application of a boron fertilizer at the critical flowering period, rather than preventive applications of diflubenzuron, is likely responsible for the yield increases. Results from this study and previous research in Louisiana (Boethel 1991, Leonard 1991) evaluating preventive applications of diflubenzuron + benomyl indicate diflubenzuron may influence yield most when a pest it is capable of controlling (velvetbean caterpillar) is present in significant numbers.

Moth of the velvetbean caterpillar, *Anticarsia gemmatalis*.

Summary and Conclusions

Effects of the insect growth regulators diflubenzuron and methoxyfenozide on soybeans and soybean insect pests were studied in the field for two years. An alternative management strategy, whereby insect growth regulators are applied in a preventive manner at the R2 to R3 growth stage, was evaluated for efficacy against late-season soybean insect pests and impact on yield. The occurrence of velvetbean caterpillar in soybean maturity groups commonly planted in southern Louisiana was studied to determine when a preventive management program with diflubenzuron may optimally be used. Information also was obtained on the effect of diflubenzuron, applied alone, and in combination with boron, for soybean yield enhancement.

Diflubenzuron and methoxyfenozide, applied at the R2 to R3 growth stage, were highly effective against velvetbean caterpillar. Diflubenzuron, applied in excess of the labeled rate, was ineffective against soybean looper, but methoxyfenozide also was applied preventive and demonstrated residual activity. Control with methoxyfenozide was comparable when applied preventive at 0.0625 and 0.125 lb ai/acre and formulated as either a wettable powder or a flowable. *Lambda*-cyhalothrin and spinosad, and thiodicarb and methoxyfenozide, applied as needed against economic threshold populations of velvetbean caterpillar and soybean looper, respectively, also were effective. Insect growth regulators did not suppress or control the soybean stink bug complex. At the Baton Rouge location in 2000, plots treated with *lambda*-cyhalothrin for velvetbean caterpillar did not require an additional treatment for stink bugs; whereas, stink bugs reached an economic threshold in diflubenzuron-treated plots. Studies at this location indicated if damaging populations of velvetbean caterpillar and southern green stink bugs occur simultaneously or close in time, a preventive management approach may be an unnecessary production input if a class of insecticide recommended for control against both insect pest species is used.

Currently, the diflubenzuron preventive program is practiced in south Louisiana, where the program appears most appropriate because the velvetbean caterpillar is historically a management concern. Our studies demonstrated maturity group IV soybeans planted in mid-April and maturity group V soybeans planted in early May escaped damaging infestations of velvetbean caterpillar. A preventive management program for velvetbean caterpillar should not be recommended for an early maturing, group IV soybean; however, this program could be considered if planting of maturity group V soybeans is delayed. Maturity group VI and VII soybeans were most susceptible to velvetbean caterpillar infestations that occurred beginning in early August. A preventive management program would be most appropriate for late maturing soybean varieties.

Yield enhancement with diflubenzuron, applied alone or in combination with boron, was not demonstrated. At the St. Gabriel location, diflubenzuron and boron-treated plots were oversprayed season long for total insect control. In the absence of insect pressure, the use of these compounds did not result in seed yields higher than those in nontreated plots. When seed weights were compared, there were no significant differences among treatments. Analysis of soybean leaves (diflubenzuron-treated and nontreated) for nutrient content at the R2-R3 growth stage indicated boron levels were in a sufficient range for soybean seed production. Yield enhancement with diflubenzuron and boron in soybean may be most related to insect control or alleviation of boron deficiences with the insecticide or fertilizer component, respectively, rather than a physiological phenomenon.

Today, IPM programs for soybean serve as an effective, economical and practical strategy for managing insect pests. Soybean IPM was developed to manage pest resistance, secondary pest resurgence and destruction of beneficial insects. These were problems characteristic of cropping systems based on use of a limited number of management tactics, predominantly insecticides. IPM for soybean is a balanced strategy: exploiting natural control provided by parasitoids, predators and entomopathogens; planting early maturing varieties as trap crops and to avoid late-season migratory lepidopteran pests; routinely sampling plants beginning at flowering; and observing economic thresholds. Few would consider a preventive insect management strategy for soybean necessary.

An alternative, preventive management strategy has potential use in Louisiana under the following circumstances:

1) In southern Louisiana, if maturity group VI or VII soybeans are planted in a location that historically has problems with velvetbean caterpillar, diflubenzuron and methoxyfenozide may be applied at the R2 to R3 growth stage for control of late season infestations. *Methoxyfenozide is not registered for use on soybean in Louisiana.*

2) In cotton-soybean agroecosystems of Louisiana, where soybean loopers are of greater importance, methoxyfenozide will offer residual

control against this pest species. Methoxyfenozide potentially has a niche in this region when used similarly to diflubenzuron in southern Louisiana; however, additional field research and knowledge of the anticipated cost of application upon registration, are needed.

As with any management program, there are advantages and disadvantages. Advantages of preventive insect management include: 1) Insect growth regulators are target pest specific and considered to be relatively nontoxic to beneficial insects; therefore, pest resurgence and secondary pest outbreaks should be unlikely and 2) producers benefit by scouting less frequently and avoiding the problem of inclement weather occurring when critical late season applications are needed. Although not a direct advantage compared with using economic thresholds, resistance is less likely because velvetbean caterpillar and soybean looper are migratory pests. Today, there is little evidence of return migration, and selection is minimized with only one insecticide application. Disadvantages of this management strategy include: 1) Treatments are applied before insect populations are known; therefore, economic losses are incurred and unneeded selection pressure is placed in the environment if the pest fails to reach an economic threshold, 2) diflubenzuron is ineffective against soybean looper; therefore, if populations reach economic threshold, an additional treatment will be necessary; and 3) neither insect growth regulator has activity against stink bugs; therefore, a class of insecticides capable of controlling this pest must be applied when populations reach economic threshold.

The goal of this research was to determine if preventive applications of insect growth regulators are viable management strategies for the late-season pest complex on soybeans and if diflubenzuron, applied alone or in combination with boron, causes soybean yield enhancement. After two years of field studies in Louisiana, it can be concluded that:

1) A preventive management strategy for soybean insects may be practical; however, use should be limited to circumstances that meet specific criteria.

2) Diflubenzuron and boron did not cause enhanced soybean yield in the absence of damaging insect populations and boron deficiency.

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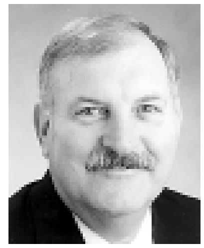
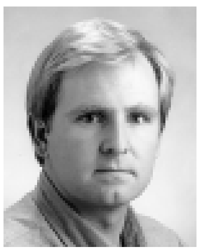
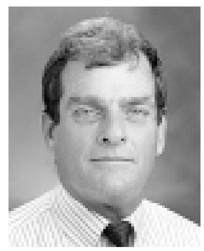
Melissa M. Willrich
Graduate Student
Department of Entomology
Louisiana Agricultural
Experiment Station
LSU AgCenter
Baton Rouge, LA 70803



David J. Boethel, Ph.D.
Associate Vice Chancellor
Louisiana Agricultural
Experiment Station
LSU AgCenter
Baton Rouge, LA 70803



B. Rogers Leonard, Ph.D.
Professor
Macon Ridge Research
Station
Louisiana Agricultural
Experiment Station
LSU AgCenter
Winnsboro, LA 71295



David C. Blouin, Ph.D.
Associate Dean
Department of Experi-
mental Statistics
Louisiana Agricultural
Experiment Station
LSU AgCenter
Baton Rouge, LA 70803

Louisiana Agricultural Experiment Station
Louisiana State University Agricultural Center
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