Interactions in Entomology: Mid-Season Dimilin and Boron Treatment Impact on the Incidence of Arthropod Pests and Yield Enhancement of Soybeans[1]

R. M. McPherson[2] and G. J. Gascho[3]

The University of Georgia, College of Agriculture and Env. Sciences, Coastal Plain Experiment Station, Tifton, GA 31793-0748 USA

J. Entomol. Sci. 34(1): 17-30 (January 1999)

Abstract Twelve replicated soybean field trials were conducted in 1993-1997 to evaluate the effects of a foliar application of the insect growth regulator Dimilin® (0.07 or 0.035 kg AI/ha) and the plant nutrient boron (0.28 kg nutrient/ha) on the incidence of insect pests and the enhancement of yield and quality. Dimilin (diflurbenzuron) was very effective at all test locations in controlling velvetbean caterpillars, *Anticarsia gemmatalis* Hübner, for the remainder of the season once the foliar application was made on soybeans in the R^2 (full bloom) to R_5 (pods filling with seeds) growth stage. Six of the test sites had significant yield increases in the Dimilin plots due to protection from economic crop injury from this pest. Dimilin was not effective in controlling stink bugs, primarily *Nezara viridula* (L.) and *Euschistus servus* (Say), and Mexican bean beetles, *Epilachna varivestis* Mulsant. Scout® (tralomethrin) and MVP® (*Bacillus thuringiensis* Berliner) did not provide adequate residual pest control when combined with the boron treatment. Yield enhancements from boron (Solubor®, soluble disodium octaborate tetrahydrate) were observed in seven tests, but yields were significantly higher than the no boron treatments in only three experiments. The nutrient applications did not influence the abundance of arthropod pests at any test location. The overall soybean yield enhancement of around 440 kg/ha (6.5 bu/a) above the untreated plots represents a positive net economic return for the total investment of around $55 per ha. Dimilin accounted for most of the yield increase due to effective pest control, but the addition of boron costs very little ($3.00/ha) with a return of about 35 kg/ha across all soil types (higher response in sandy soils). It appears that a dimilin/boron foliar application around R_3 stage soybeans (small pods forming) can be a profitable strategy in south Georgia, especially in areas where velvetbean caterpillars are annual economic pests and the fields contain sandy soil with low levels of available boron.

Key Words Solubor, diflurbenzuron, *Glycine max, Anticarsia gemmatalis, Nezara viridula, Euschistus servus, Epilachna varivestis*, crop protection, pest management.

Several arthropod pests cause annual crop losses to soybean, *Glycine max* (L.) Merrill, produced throughout the United States (Higley and Boethel 1994). Economic losses due to soybean insect pests can exceed $25 million in some years in Georgia due to crop damage and insecticide controls (Douce and McPherson 1991). Stink bugs, primarily *Nezara viridula* (L.) and *Euschistus servus* (Say), velvetbean cater-

[1]Received 13 August 1998; accepted for publication 08 October 1998.

[2]Department of Entomology

[3]Department of Crop & Soil Sciences

pillars, *Anticarsia gemmatalis* Hübner, and soybean loopers, *Pseudoplusia includens* (Walker), are routinely the most damaging pests of Georgia's soybean crop (McPherson et al. 1996). Dimilin® (diflubenzuron 25 WP and 2L, Uniroyal Chemical Co., Middleburg, CT) is an insect growth regulator that has been reported to provide excellent long-term control of velvetbean caterpillars and green cloverworms, *Plathypena scabra* (F.) (Yanes and Boethel 1985, Hammond and Nettleton 1984), fair control of soybean loopers (Yanes and Boethel 1985), and poor control of stink bugs (Yanes and Boethel 1985). This material is much less toxic to mammals and other non-target organisms (Uniroyal Chemical 1993) than most of the standard insecticides currently being applied on soybeans. Due to its effectiveness on controlling certain soybean insect pests and its relative safety to the environment, dimilin provides an alternative insecticidal tactic that fits the integrated pest management concept.

Boron is an important nutrient for many crops, including soybean. Yield responses have been reported when boron (Solubor®, soluble disodium octaborate tetrahydrate, U.S. Borax Inc., Valencia, CA) was applied on soybeans produced in soils with high pH, low organic matter, low available boron, low cation exchange capacity, and coarse texture (Al-Molla 1985). More recently, soybean yield responses have been reported to fertigation, soil-applied, and foliar-applied boron (Schon and Blevins 1989, Gascho 1992, Gascho and McPherson 1997). Mechanisms that cause these yield responses to boron include increased seed size, decreased flower and pod abortion, improved carbon mobilization to roots, improved nitrogen fixation, improved membrane function, and improved pollen germination and pollen tube growth (Gascho and McPherson 1997).

Combining a boron application with a dimilin treatment in soybean fields where boron yield responses are likely and velvetbean caterpillar infestations approach the economic injury level most years could prove to be an efficient and effective soybean production practice. This study was undertaken to examine the combined effects of dimilin and boron on soybean arthropod pest infestations and the potential for yield and quality enhancement with minimal production costs.

Materials and Methods

Twelve field experiments were conducted in Tift, Decatur, and Sumter counties in southern Georgia during 1993-1997. Soybean seeds were planted in plots measuring 7.6 m long and 3.6 m wide (4 rows). The plots were arranged in a repeated measures (sampling dates) randomized complete block design with four to six replications with a factorial arrangement of treatments in 1994 and 1995. Insecticide and nutrient levels served as the factors to be examined in these field experiments. The insecticide and nutrient treatments and treatment combinations were usually applied to the soybeans during the R_3 growth stage (Fehr and Caviness 1977) when small pods were developing, but at some test sites the treatments were also applied at R_2 (full bloom), R_4 (full pod development) or R_5 (pods beginning to fill with seeds). Standard tillage, pre-plant fertilization (0-10-20), and herbicide programs were followed. All plots were essentially weed free (some weeding by hand was done when necessary) and no pre-plant or post-emergence insecticides were applied except in the specific insecticide treatment plots. The insecticide and boron treatments were applied with a CO_2 backpack sprayer delivering 187L per ha at 276 k Pa.

All plots were monitored weekly after the treatments were applied and continued for either 35 days (if the crop was beginning to senesce) or 42 days by taking a 25-sweep sample from each plot. A 38-cm diam net was passed through the foliage of a single row (Kogan and Pitre 1980) and the 25-sweep sample was placed in a plastic bag, labeled, frozen and examined at a later date. All the arthropods in each bag were identified and recorded. On the last sample date plots were visually rated for percent defoliation. Twenty-five random plants were collected from each plot and scanned with a portable area meter (LiCor, Lincoln, NB) to validate the visual estimates. At maturity, plots were harvested each year with a small plot combine, and yield and seed weight were determined. The insect count, defoliation, yield and seed weight data were analyzed with an analysis of variance (P = 0.05) and treatment means were separated with LSD's (SAS Institute 1989). Paired t-tests (P = 0.05) also were conducted to compare dimilin vs. no dimilin and boron vs. no boron.

1993 test. This experiment was conducted on a Coastal Plain Experiment Station farm site in Tift Co., Georgia. 'Pioneer 9761' soybeans were planted in late June, following the harvest of wheat in a Tifton loamy sand soil. The dimilin and boron (Solubor®) were applied in late August to R_3 stage soybeans at rates of 0.07 kg AI and 0.28 kg per ha, respectively. These plots were not irrigated throughout the growing season.

1994 tests. In 1994, three Georgia Agricultural Experiment Station test locations were used in Tift, Decatur, and Sumter counties. The Tift Co. site was planted in mid-May with 'Cook' soybeans under a conventional full-season system in a Tifton loamy sand soil that changed to a Fuquay loamy sand soil. This test was irrigated twice during water deficit periods in the season. The Decatur Co. site was also planted in mid-May with Cook soybeans in a Norfolk sandy loam soil. This test was irrigated four times during the season. The Sumter Co. test was planted in late-May with 'Braxton' soybeans in a Greenville sandy clay loam soil that was irrigated several times. All three test sites evaluated the same five insecticide treatments and eight nutrient treatments. The treatments were applied in early to mid-August when the soybeans were in the R_3 stage of plant growth. The dimilin 25WP and Scout Xtra®

Table 1. Effects of dimilin (0.07 kg AI/ha) and boron (Solubor, 0.028 kg/ha) on the peak abundance of velvetbean caterpillars, percent defoliation, seed weight and yield (±SEM) on soybeans, Tift Co. Georgia, 1993.

Treatment*	Larvae per 25 sweeps**	Percentage⁺ defoliation	Yield kg/ha	100-seed wt (gm)
Dimilin 25 WP only	2.3 ± 1.7	3.5 ± 2.0	2630 ± 227	18.5 ± 1.0
Dimilin + Boron	1.5 ± 1.3	2.5 ± 1.3	2865 ± 235	19.0 ± 1.3
Boron only	36.3 ± 5.2	30.2 ± 3.4	2885 ± 208	19.2 ± 1.3
F value	12.25	28.60	1.37	2.22
df	2,24	2,6	2,6	2,6
$P > F$	0.01	0.01	0.42	0.25

* Treatments applied on R_3 growth stage (pods forming) soybeans.
** Peak occurred on 21 September.
⁺ Percent of total foliage removed.

Table 2. Effects of selected insecticide and nutrient combinations on the seasonal abundance of velvetbean caterpillars and Mexican bean beetles (±SEM) on soybeans at three Georgia county locations, 1994.

	Velvetbean caterpillars per 25 sweeps			Mexican bean beetles per 25 sweeps (Tift)
Treatment*	Tift	Decatur	Sumter	
Dimilin	0.8 ± 0.7c	0.7 ± 0.3c	0.1 ± 0.07c	6.1 ± 0.4a
MVP	6.1 ± 1.3a	6.8 ± 0.5a	0.6 ± 0.10a	7.1 ± 0.5a
Scout	6.4 ± 1.0a	6.7 ± 0.4a	0.4 ± 0.05b	2.5 ± 0.4b
Scout-2 appl.	3.2 ± 0.5b	5.6 ± 0.6b	0.4 ± 0.03b	1.7 ± 0.5b
No insecticide	6.1 ± 1.0a	6.3 ± 0.5ab	0.7 ± 0.08a	6.6 ± 0.6a
Nitrogen	4.2 ± 0.3a	5.4 ± 0.7a	0.6 ± 0.10a	5.0 ± 0.5a
Magnesium	5.1 ± 0.3a	5.0 ± 0.5a	0.5 ± 0.07a	4.9 ± 0.3a
Boron	4.4 ± 0.5a	5.5 ± 0.8a	0.4 ± 0.09a	4.8 ± 0.5a
N + MG	4.4 ± 0.7a	5.2 ± 0.5a	0.4 ± 0.09a	5.2 ± 0.7a
N + B	4.3 ± 0.3a	5.4 ± 0.7a	0.4 ± 0.11a	4.4 ± 0.4a
Mg + B	4.2 ± 0.4a	4.9 ± 0.5a	0.6 ± 0.08a	5.1 ± 0.4a
N + Mg + B	4.4 ± 0.3a	5.7 ± 0.6a	0.4 ± 0.09a	4.6 ± 0.5a
No nutrient	4.6 ± 1.0a	4.6 ± 0.6a	0.4 ± 0.07a	4.5 ± 0.3a
	Statistical analysis *P* > *F*			
Rep	0.01	0.01	0.71	0.01
Insecticide	0.01	0.01	0.01	0.01
Nutrient	0.72	0.46	0.41	0.28
Ins. × Nut.	0.23	0.80	0.21	0.36
Rep (Ins. × Nut.)	0.70	0.11	0.31	0.01
Date	0.01	0.01	0.01	0.01
Ins. × Date	0.01	0.01	0.01	0.01
Nut. × Date	0.80	0.75	0.36	0.62
Ins. × Nut. × Date	0.19	0.98	0.42	0.37

* Treatments applied on R_3 growth stage (pods forming) soybeans. Column means with the same letter are not significantly different (LSD, $P = 0.05$).

(AgrEvo, Wilmington, DE) were applied at rates of 0.035 and 0.023 kg AI per ha, and MVP (*Bacillus thuringiensis*) (Mycogen Corp., San Diego, CA) was applied at a rate of 1168 ml (formulation) per ha. The boron (Solubor), nitrogen (Urea), and magnesium (epsum salts) were applied at rates of 0.28, 11.2, and 0.28 kg of nutrient per ha, respectively.

Table 3. Effects of selected insecticide and nutrient combinations on the seasonal abundance of stink bugs (±SEM) on soybeans at three Georgia locations, 1994.

	Stink bugs per 25 sweeps**		
Treatment*	Tift	Decatur	Sumter
Dimilin	4.1 ± 0.3a	5.5 ± 0.7a	0.4 ± 0.10b
MVP	4.5 ± 0.5a	5.2 ± 0.4a	0.6 ± 0.07a
Scout	3.1 ± 0.3b	4.6 ± 0.5ab	0.2 ± 0.11bc
Scout-2 applications	2.0 ± 0.3c	3.7 ± 0.4b	0.1 ± 0.04c
No insecticide	4.2 ± 0.6a	4.8 ± 0.4a	0.4 ± 0.09b
Nitrogen	3.3 ± 0.4a	4.7 ± 0.5a	0.4 ± 0.08a
Magnesium	3.7 ± 0.7a	4.3 ± 0.7a	0.3 ± 0.10a
Boron	3.7 ± 0.7a	5.2 ± 0.3a	0.2 ± 0.07a
N + MG	3.9 ± 1.0a	5.0 ± 0.4a	0.2 ± 0.07a
N + B	3.9 ± 0.3a	4.9 ± 0.4a	0.2 ± 0.09a
Mg + B	2.8 ± 0.4a	4.7 ± 0.5a	0.3 ± 0.10a
N + Mg + B	4.2 ± 0.6a	5.2 ± 1.1a	0.4 ± 0.10a
No nutrient	3.0 ± 0.5a	4.2 ± 0.7a	0.2 ± 0.07a
	Statistical analyses $P > F$		
Rep	0.05	0.01	0.02
Insecticide	0.01	0.01	0.01
Nutrient	0.14	0.48	0.63
Ins. × Nut.	0.40	0.13	0.75
Rep (Ins. × Nut.)	0.18	0.01	0.67
Date	0.01	0.01	0.11
Ins. × Date	0.01	0.06	0.23
Nut. × Date	0.01	0.24	0.32
Ins. × Nut. × Date	0.72	0.22	0.85

* Treatments applied on R_3 growth stage (pods forming) soybeans.

** Primarily the southern green stink bug, but also some brown and green stink bugs. Column means with the same letter are not significantly different (LSD, $P = 0.05$).

At a separate test site in Tift Co., the same three insecticide treatments (dimilin, Dipel, and Scout) were evaluated at the same rates used in the other 1994 test for their residual control of velvetbean caterpillars. The treatments were applied on 3 August to 'Davis' soybeans that were in the R_3 growth stage. The plots were 18.2 m long × 5.5 m wide (6 rows), and the foliar sprays were applied with a CO_2-powered

Table 4. Effects of selected insecticide and nutrient combinations on percent defoliation (±SEM) caused primarily by velvetbean caterpillars on soybeans at three Georgia locations, 1994.

Treatment*	Percent defoliation**		
	Tift	Decatur	Sumter
Dimilin	7.1 ± 2.2d	3.3 ± 3.2b	1.3 ± 0.6c
MVP	24.3 ± 2.8b	30.8 ± 6.8a	6.2 ± 1.5a
Scout	15.0 ± 3.1c	26.7 ± 6.3a	5.0 ± 1.0a
Scout-2 applications	6.8 ± 2.4d	9.1 ± 3.7b	3.2 ± 0.7b
No insecticide	32.5 ± 3.2a	32.4 ± 7.4a	6.3 ± 2.1a
Nitrogen	18.1 ± 2.1a	20.3 ± 4.3a	4.2 ± 2.0a
Magnesium	17.3 ± 1.4a	21.4 ± 3.2a	3.8 ± 0.7a
Boron	17.3 ± 3.2a	20.0 ± 3.5a	4.0 ± 0.8a
N + MG	17.7 ± 3.1a	22.3 ± 6.6a	4.2 ± 1.9a
N + B	16.5 ± 3.8a	19.4 ± 4.1a	3.9 ± 0.8a
Mg + B	16.9 ± 1.7a	20.8 ± 4.3a	5.3 ± 0.6a
N + Mg + B	18.2 ± 4.0a	21.2 ± 6.2a	4.2 ± 0.6a
No nutrient	18.3 ± 1.3a	20.5 ± 6.1a	4.5 ± 1.8a
	Statistical analyses $P > F$		
Rep	0.05	0.20	0.01
Insecticide	0.01	0.01	0.01
Nutrient	0.44	0.32	0.30
Ins. × Nut.	0.48	0.62	0.38

* Treatments applied on R_3 growth stage (pods forming) soybeans.

** Percent of total foliage removed. Column means with the same letter are not significantly different (LSD, P = 0.05).

backpack sprayer delivering 187L per ha at 276 k Pa. These treatments plus an untreated check were arranged in a randomized block design with four replications. All plots were sampled 2, 7, 14, 21, 28, 35, 42 and 49d after treatment (DAT) by taking a 25-sweep sample through the foliage of a single row, as previously described. All velvetbean caterpillar larvae were counted and recorded from each sample and distribution curves were constructed for each treatment.

1995 test. This test was conducted in Tift Co. on Davis soybeans planted in mid-May in a Tifton loamy sand soil. Five insecticide and three nutrient treatments were applied in mid-August when the soybeans were in the R_3 stage of plant growth. This test site was irrigated three times during the season. The dimilin, Scout, boron and nitrogen were applied at the same rates as in the 1994 tests.

1996 test. This study was also conducted in Tift Co. on Davis soybeans planted

Table 5. Effects of selected insecticide and nutrient combinations on soybean yields (±SEM) at three Georgia locations, 1994.

	Kilograms per hectare		
Treatment*	Tift	Decatur	Sumter
Dimilin	3786 ± 160b	3180 ± 141a	2856 ± 263a
MVP	3436 ± 188c	3031 ± 109a	2789 ± 270a
Scout	3658 ± 276bc	3173 ± 132a	3254 ± 199a
Scout-2 applications	4136 ± 185a	3382 ± 112a	3281 ± 228a
No insecticide	3382 ± 177c	3153 ± 117a	2930 ± 188a
Nitrogen	3658 ± 223a	3254 ± 106ab	3058 ± 212a
Magnesium	3678 ± 212a	3139 ± 130bc	2910 ± 208a
Boron	3692 ± 175a	3213 ± 155abc	2930 ± 185a
N + MG	3799 ± 190a	3038 ± 105c	2883 ± 273a
N + B	3779 ± 254a	3247 ± 102ab	2977 ± 175a
Mg + B	3671 ± 225a	3382 ± 112a	3166 ± 310a
N + Mg + B	3651 ± 166a	3207 ± 163abc	2998 ± 215a
No nutrient	3611 ± 190a	3267 ± 121ab	3112 ± 203a
	Statistical analyses $P > F$		
Rep	0.05	0.47	0.30
Insecticide	0.01	0.33	0.28
Nutrient	0.25	0.05	0.15
Ins. × Nut.	0.22	0.41	0.63

* Treatments applied on R_3 growth stage (pods forming) soybeans. Column means with the same letter are not significantly different (LSD, $P = 0.05$).

in mid-May in a Fuquay loamy sand soil. Two insecticide and four boron treatments were applied at different soybean growth stages (R_3-R_5). The dimilin and boron were applied in mid- to late-August at the same rates as in the 1994 tests. This test was irrigated twice during the early part of the growing season. The individual test plots were not sampled for insect pests in 1996. However, the remaining one-half of the test field that was not treated with dimilin or boron was monitored weekly from R_2 to harvest to monitor the pest populations at the test site.

1997 tests. The 1997 tests were conducted in Tift Co. in six separate fields planted in adjacent terraces in early-June in Fuquay loamy sand soil. Each field was planted in either 'RA452', 'Delta Pine 105', Davis, 'Boggs', 'Braxton' and 'Cobb' soybeans. Five boron treatments (0.28 kg per ha) were applied during August at four different soybean growth stages (R_2-R_5) or not applied at all ('no boron'). All the boron treatments received a foliar treatment of dimilin at 0.035 kg AI/ha at R_3 development.

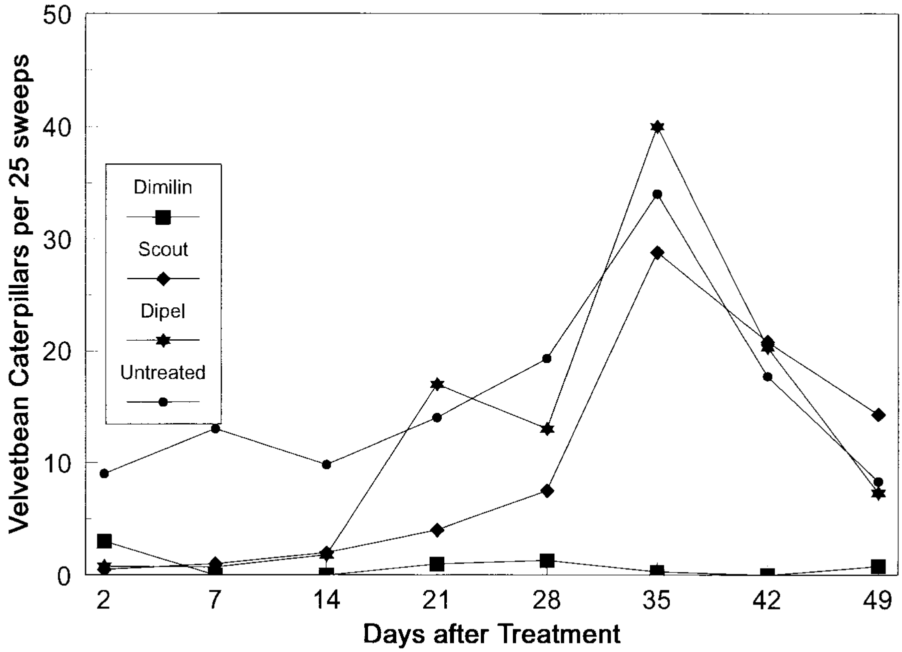

Fig. 1. The seasonal distribution of velvetbean caterpillars on 'Davis' soybeans treated on 3 August (R_3 stage soybeans) with Dimilin 25 WP 0.035 kg AI/ha, Scout Xtra 0.023 kg AI/ha, Dipel ES 1168 ml (formulation)/ha, or no insecticides.

The untreated plots received no dimilin or boron. This test site was irrigated twice during the early part of the growing season. The test plots in each of these six fields were not monitored for insect pest densities. However, the remaining one-third of each field that was not treated with dimilin or boron was sampled weekly from R_2 to harvest to document the species and abundance of arthropod pests in each test field.

Results and Discussion

1993 tests. The dimilin and dimilin + boron significantly reduced the population levels of velvetbean caterpillars ($F = 12.25$, 2 and 24 df, $P < 0.01$) and the percentage defoliation ($F = 28.60$, 2 and 6 df, $P < 0.01$) on soybeans compared to the boron only treatment (Table 1). No differences were noted for yields or 100-seed weights, although there was a trend towards higher levels in the boron plots. At the time that dimilin and boron were applied on 24 August, velvetbean caterpillar population densities were around 7 to 10 larvae per 25 sweeps. Populations peaked 28 DAT at 36 larvae per 25 sweeps in the untreated plots (no dimilin), exceeding the treatment threshold of 35 larvae per 25 sweeps. Populations remained very low (1 to 2 larvae per 25 sweeps) in the dimilin plots on all sampling dates up to 42 DAT.

1994 tests. Velvetbean caterpillar population densities were much higher in Tift

Table 6. Effects of selected insecticide and nutrient combinations on the seasonal abundance of stink bugs and velvetbean caterpillars, yield, and percent defoliation (±SEM) on soybeans, Tift Co. Georgia, 1995.

	Insects per 25 sweeps			
Treatment*	Stink bugs	Velvetbean caterpillars	Yield kg/ha	Percent defoliation**
Dimilin	2.4 ± 0.3b	0.8 ± 1.0d	3173 ± 316a	5.6 ± 3.1c
Scout	1.8 ± 0.3bc	2.8 ± 2.1b	3348 ± 229a	13.8 ± 4.1b
Scout-2 appl.	1.4 ± 0.5c	1.9 ± 1.8c	3281 ± 309a	7.4 ± 3.3bc
Dimilin/Scout	1.8 ± 0.6bc	0.8 ± 1.0d	3308 ± 282a	4.8 ± 2.4c
No insecticide	3.2 ± 0.4a	6.2 ± 2.4a	3186 ± 222a	28.3 ± 5.4a
Boron	1.6 ± 0.4a	1.6 ± 1.6a	3254 ± 282a	8.5 ± 4.0a
Boron + Nitrogen	1.9 ± 0.6a	1.6 ± 1.5a	3227 ± 230a	8.2 ± 4.1a
No nutrient	2.2 ± 0.4a	2.2 ± 1.8a	3172 ± 226a	10.3 ± 4.5a
	Statistical analyses $P > F$			
Rep	0.45	0.01	0.01	0.15
Insecticide	0.01	0.01	0.11	0.01
Nutrient	0.16	0.90	0.18	0.23
Ins. × Nut.	0.32	0.91	0.01	0.16

* Treatments applied on R_3 growth stage (pods forming) soybeans. Column means with the same letter are not significantly different (LSD, $P = 0.05$).

** Percent of total foliage removed.

and Decatur counties than in Sumter Co. in 1994 (Table 2). Dimilin was very effective in reducing the seasonal mean populations at all three locations, and especially in Tift and Decatur counties where the mean from six sample dates (weekly for 42 DAT) exceeded 6 caterpillars per 25 sweeps in the untreated plots. Two applications of Scout (applied at R_3 and 10 days later) reduced the velvetbean caterpillars below some of the other treatments; however, this treatment was very expensive ($50 per ha) and not nearly as effective as the single application of dimilin at 0.035 kg AI/ha. The different nutrient levels applied in these three tests did not affect the seasonal populations of velvetbean caterpillars (Table 2). The dimilin and MVP treatments did not impact the Mexican bean beetle, *Epilachna varivestis* Mulsant, populations at the Tift Co. site, where seasonal means exceeded 6 beetles per 25 sweeps (Table 2). The single and two applications of Scout were effective in controlling these beetles, but no nutrient level effects were observed to impact Mexican bean beetle populations. The Scout treatments were also the only effective controls of stink bug pests (primarily the southern green stink bug) at all the test sites. The nutrient treatments did not influence stink bug densities (Table 3).

The percentage defoliation was significantly lower in the dimilin and two scout

Table 7. Effects of selected insecticide and nutrient combinations on the seed weight, percent defoliation, and yield (±SEM) on soybeans, Tift Co. Georgia, 1996.

Treatment*	Percent defol.**	100-seed wt (gm)	Yield kg/ha
Untreated	15.5 ± 3.1	17.1 ± 1.0	3820 ± 255
Dimilin R_4	3.7 ± 1.7	17.2 ± 0.7	3922 ± 270
Dimilin R_3, R_5	2.7 ± 1.3	17.2 ± 1.1	3853 ± 218
Dimilin R_3, R_4, R_5	3.0 ± 1.8	17.4 ± 1.0	3927 ± 315
Boron R_4	10.7 ± 1.9	17.0 ± 0.7	3941 ± 280
Boron R_3, R_5	10.0 ± 1.5	17.3 ± 0.6	3717 ± 266
Boron R_3, R_4, R_5	12.5 ± 3.1	17.5 ± 0.7	3799 ± 210
Dim + B R_4	3.8 ± 1.8	17.1 ± 1.0	3880 ± 183
Dim + B R_3, R_5	2.7 ± 1.5	16.7 ± 0.8	3745 ± 225
Dim + B R_3, R_4, R_5	2.3 ± 1.5	17.3 ± 0.8	3918 ± 215
F value	28.96	0.40	1.42
df	9,45	9,45	9,45
P > F	0.01	0.93	0.21

* Treatments applied at R_3 (pods forming), R_4 (full-size pods) and R_5 (pods filling with seeds) soybean growth stages.

** Percent of total foliage removed.

application treatments than in all the other treatments, including the untreated plots (Table 4). At the Tift Co. site, defoliation in the MVP and one Scout application was also lower than in the untreated. No nutrient level effects were noted for defoliation at any of the three sites (Table 4). Yields were significantly higher in the Scout two applications and Dimilin treatments than in the untreated plots at the Tift County site, but no yield differences were detected between insecticide treatments at the other two sites (Table 5). The boron + magnesium treatment did have a higher yield than some of the other nutrient levels at the Decatur site, but no other nutrient differences were observed for yield (Table 5).

Population densities of velvetbean caterpillars were very low in the dimilin plots on all sampling dates up to 49 DAT (Fig. 1), when sampling was discontinued because the soybeans were maturing. The Dipel treatment was effective for up to 14 DAT, then populations rapidly increased, peaking at 35 DAT at population densities higher than in the untreated plots. The Scout treatment suppressed velvetbean caterpillar populations for up to 28 DAT, then populations rose to peak population densities on 35 DAT at levels below those in the untreated plots. These seasonal abundance data demonstrate the need for a long-residual material, like dimilin, to be combined with the boron treatment that needs to be applied to soybeans in the R_3 growth stage. Materials like Dipel and Scout are very effective for controlling velvetbean caterpillars. However, these pests are just beginning to develop in most soybeans when the boron

Table 8. Effects of selected boron/dimilin applications on the percentage defoliation (±SEM) caused by velvetbean caterpillars on six soybean varieties in Maturity Groups IV-VIII, Tift Co. Georgia, 1997.

	Percentage defoliation**					
Treatment*	RA452 (IV)	DP105 (V)	Boggs (VI)	Davis (VI)	Braxton (VII)	Cobb (VIII)
No Boron	6.0 ± 3.8	5.8 ± 1.5	7.2 ± 2.8	8.8 ± 3.1	6.8 ± 1.5	8.5 ± 3.3
Boron R_2	5.3 ± 2.1	5.0 ± 1.3	8.4 ± 2.5	9.3 ± 3.5	8.3 ± 1.5	9.0 ± 1.8
Boron R_3	4.3 ± 2.8	5.5 ± 2.1	7.3 ± 3.1	8.0 ± 3.3	5.3 ± 1.0	9.5 ± 3.0
Boron R_4	4.5 ± 1.7	5.3 ± 1.6	7.1 ± 2.7	8.2 ± 1.5	6.2 ± 1.3	7.3 ± 2.5
Boron R_5	5.1 ± 3.1	4.8 ± 0.8	8.0 ± 3.0	7.0 ± 2.8	6.0 ± 2.8	10.1 ± 5.5
Untreated	40.0 ± 5.3	45.0 ± 5.8	90.0 ± 7.7	86.3 ± 5.0	73.5 ± 4.1	95.3 ± 6.5
F value	10.56	6.71	14.21	12.35	8.88	7.75
df	5,15	5,15	5,15	5,15	5,15	5,15
P > F	0.01	0.01	0.01	0.01	0.01	0.01

* All treatments received an application of Dimilin at 0.035 kg AI/ha at R_3 growth stage except the untreated plots which received no Boron or Dimilin. Soybean growth stages: R_2-full bloom, R_3-small pods forming, R_4-full pods but no seeds, R_5-pods filling with seeds.

** Percent of total foliage removed.

is needed, so short residual materials (even those lasting 14-21 DAT) will be ineffective for season-long control of this pest if applied with the boron treatment.

1995 test. All four of the insecticide treatments significantly reduced the seasonal mean velvetbean caterpillar and stink bug populations below the untreated plots in 1995 (Table 6). The percentage defoliation was also lower in the treated plots; however, yields were not different between treatments. The dimilin and dimilin + Scout treatments provided the most effective long-term control of velvetbean caterpillars and had the lowest amount of defoliation. Although yields were not different, there was a trend in higher yields in the plots treated with Scout. This was probably due to the velvetbean caterpillar and stink bug control provided by this product and a resultant reduction in stink bug damaged kernels. Stink bug feeding is reported to reduce soybean seed size and yield (McPherson et al. 1993).

1996 test. Dimilin reduced the percentage defoliation caused by velvetbean caterpillars regardless of whether it was applied alone or with boron at the R_3, R_4 or R_5 soybean growth stage (Table 7). The boron applied alone at the R_4 soybean growth stage also had lower defoliation than in the untreated plots; however, the percentages were low and ranged from 10.0% in the plots treated with boron at R_3 and R_5 to 15.5% in the untreated plots. The treatment threshold based on defoliation is 15% from full bloom to pods filled with seeds and then 25% after the pods have filled with seeds. The velvetbean caterpillar population density in the untreated portion of this field was relatively low throughout the entire season. Populations peaked in early September (R_5 soybean growth stage) at only 12 larvae per 25 sweeps. Thus, the low percent defoliation in the untreated plots (15.5%) was not surprising. Stink bugs were present

Table 9. Effects of selected boron/dimilin applications on the yield (±SEM) of six soybean varieties in Maturity Groups IV-VIII, Tift Co. Georgia, 1997.

	Yield in kilograms per hectare					
Treatment*	RA452 (IV)	DP105 (V)	Boggs (VI)	Davis** (VI)	Braxton (VII)	Cobb (VIII)
No Boron	1751 ± 212	2149 ± 122	2391 ± 369	1314 ± 271	1556 ± 309	2957 ± 271
Boron R_2	1947 ± 235	2129 ± 147	2405 ± 411	1137 ± 212	1758 ± 328	2924 ± 310
Boron R_3	1832 ± 209	2162 ± 210	2284 ± 415	1219 ± 250	1866 ± 360	2883 ± 250
Boron R_4	2014 ± 255	2086 ± 176	2425 ± 235	1165 ± 288	1718 ± 305	3085 ± 263
Boron R_5	1819 ± 198	2169 ± 155	2600 ± 275	1091 ± 216	1441 ± 280	2876 ± 312
Untreated	1792 ± 190	1853 ± 164	1401 ± 402	761 ± 205	788 ± 244	1213 ± 340
F value	1.55	2.77	11.47	3.77	6.05	15.40
df	5,15	5,15	5,15	5,15	5,15	5,15
Pr > F	0.23	0.08	0.01	0.04	0.01	0.01

* All treatments received an application of Dimilin at 0.035 kg AI/ha at R_3 growth stage except the untreated plots which received no Boron or Dimilin. Soybean growth stage: R_2-full bloom, R_3-small pods forming, R_4-full pods but no seeds, R_5 pods filling with seeds.

** No 1997 certified seeds were available so seeds carried over from the 1996 experiments were planted even though they had poor germination (60-65%).

in all plots and caused between 12.0 to 20.4% feeding damage to the kernels, but no treatment differences were noted. The 20% damaged kernels would equate to a 5% seed damage score by seed graders and a slight reduction in the price received. The 100-seed weights and yields were not different between the Dimilin, Boron, combinations, and the untreated plots (Table 7).

1997 tests. Velvetbean caterpillar populations were high in all the field tests in 1997, especially in the later-maturing Boggs, Davis, Braxton, and Cobb, where populations peaked at 96, 75, 105, and 117 larvae per 25 sweeps, respectively. As a result of this heavy population pressure, the percentage of defoliation was also very high for all six varieties (Table 8). The early-maturing RA452 and DP105 varieties did have lower population peaks of 44 and 70 larvae per 25 sweeps, respectively, but still had percent defoliation levels of 40 and 45 in the untreated plots. All boron plots had been treated with dimilin at the R_3 growth stage and, thus, had significantly lower defoliation levels in all varieties than in the untreated plots. These heavy velvetbean caterpillar populations and resultant high defoliation levels caused very high yield reductions in all six varieties, significantly different in four (Table 9). The untreated plot yields in the RA452 and DP105 were lower than only some of the dimilin/boron treatments. In the Maturity Groups VI-VIII where caterpillar populations were the highest, the untreated plots had much lower yields than all the other plots that were treated with dimilin and boron.

Overall response. The overall effects of dimilin, boron and dimilin + boron foliar applications on yield enhancement of soybeans in Georgia are summarized in Table 10. The 12 tests conducted during a 5-year period were evaluated over a wide range of yielding environments, maturity groups and varieties. Only three of the tests had

Table 10. The overall effects of dimilin, boron and dimilin + boron foliar applications on the yield enhancement of soybeans in Georgia, 1993-1997.

Year	Location (county)	Variety* (maturity)	Ave. yield kg/ha		Yield diff. from untreated		
			Boron	Dimilin	Boron	Dimilin	B + D
1993	Tift	P9461 (VII)	2875	2748	245.0**	−137.5	—
1994	Tift	Cook (VIII)	3692	3786	80.9	404.4**	391.0**
1994	Decatur	Cook (VIII)	3215	3180	6.7	27.0	31.3
1994	Sumter	Braxton (VII)	2932	2856	−94.4	−74.1	−80.5
1995	Tift	Davis (VI)	3254	3173	82.6	−13.5	27.0
1996	Tift	Davis (VI)	3833	3874	−47.5	54.7	27.7
1997	Tift	RA452 (IV)	1903	1873	152.0**	80.6	111.0
1997	Tift	DP105 (V)	2137	2139	−12.5	283.1**	286.0**
1997	Tift	Boggs (VI)	2429	2420	37.5	1017.7**	1027.5**
1997	Tift	Davis (VI)	1153	1185	−161.0	424.2**	392.0**
1997	Tift	Braxton (VII)	1696	1668	139.8**	879.8**	907.8**
1997	Tift	Cobb (VIII)	2942	2945	−14.7	1732.2**	1729.0**
	Test ave. (12 sites)		2672	2654	34.5	389.9	440.9

* Variety designations include P for Pioneer, RA for Ring Around, and DP for Deta Pine. Maturity groups include IV for very early maturing varieties for Georgia, to VIII for very late maturing varieties for Georgia.
** Significantly different from untreated, paired *t*-test ($P = 0.05$).

significantly higher yields in the boron plots compared to the no-boron plots, while 6 of the 12 experiments had significantly higher yields in the dimilin plots compared to the no-dimilin plots. Ten of the eleven studies where dimilin + boron were compared to plots that received no dimilin or boron had positive yield enhancements, and six of these responses were significantly higher than the untreated. It was surprising to note so few (25%) boron yield responses in soybeans. Earlier reports suggest that soybean responses to boron are common in Georgia (Gascho 1992, Gascho and McPherson 1997), although these articles stress the importance of sandy soil, low boron levels in the soil, and irrigation as key factors for this yield enhancement. All the test sites in this study were conducted on loamy soils in 1993-1996. The 1997 test site was on a Fuquay loamy soil sand, and it was on this farm where two of the three yield increases due to boron were observed. The six soybean yield responses to dimilin were all directly related to crop protection from high defoliation levels caused by velvetbean caterpillars. Dimilin was very effective in controlling velvetbean caterpillars in all 12 tests, whenever applied at the R_2-R_5 growth stage, but only six of these test sites had larval populations that caused economic injury to the crop.

Over all test locations, the dimilin/boron treatment enhanced soybean yields about 440 kg/ha (6.5 bu/a) above the untreated plots. This represents an economical return for a total investment including application costs of around $55 per ha assuming a price of $5 per bushel for soybeans. The dimilin response, which occurred in 50% of these tests, accounted for most of the yield enhancement. This was due to effectively controlling the velvetbean caterpillar, an annual economic threat to Georgia's soybean crop. Undoubtedly, more significant boron responses would have been obtained if the test sites were located in fields containing deep sandy soils deficient in boron. Most of the experiments reported in this study were on loamy soils with moderate to high levels of boron.

It appears that a dimilin-boron foliar application on R_3 soybeans can be very profitable in south Georgia—especially in areas where velvetbean caterpillars are a common pest problem, soils are sandy with low boron retention, and high production standards are followed (high yielding environments with ample irrigation). The dimilin/boron application is not likely to provide annual profitable returns in locations where velvetbean caterpillars are only sporadic or occasional pests, soils are with adequate boron retention, and where little or no irrigation is used.

Acknowledgments

The authors express sincere gratitude to B. Baldree, B. Crowe, E. Hall, and D. Taylor for their technical support, and to the Georgia Agricultural Commodity Commission for Soybeans, U.S. Borax and the Georgia Agricultural Experiment Stations for financial assistance.

References Cited

Al-Molla, R. M. M. 1985. Some phenological aspects of soybean development and yield as affected by boron fertilization. Ph.D. Dissertation. Univ. of Arkansas. Diss. Abst. 46-10B, 3268, Ann Arbor, MI.

Douce, G. K. and R. M. McPherson (eds.). 1991. Summary of losses from insect damage and costs of control in Georgia, 1989. Georgia Agric. Expt. Stn. Spec. Publ. 70: 47 pp.

Fehr, W. R. and C. E. Caviness. 1977. Stages of soybean development. Iowa State Univ. Spec. Rept. 80.

Gascho, G. J. 1992. Late-season nitrogen and boron applications for soybean. Proc. Fluid Fertilizer Foundation 1992 Research Symp. Pp. 59-67.

Gascho, G. J. and R. M. McPherson. 1997. A foliar boron nutrition and insecticide program for soybean, Pp. 11-15. *In* R. W. Bell and B. Rerkasem (eds.), Boron in Soils and Plants. Kluwer Acad. Publ. Netherlands.

Hammond, R. B. and E. Nettleton. 1984. Foliar-applied insecticide treatments on soybeans, 1983. Insecticide and Acaricide Tests: 1984. 9: 304.

Higley, L. G. and D. J. Boethel (eds.). 1994. Handbook of soybean insect pests. Entomol. Soc. Amer. Press. Lanham, MD. 136 pp.

Kogan, M. and H. N. Pitre, Jr. 1980. General sampling methods for above-ground populations of soybean arthropods, Pp. 30-60. *In* M. Kogan and D. C. Herzog (eds.), Sampling Methods in Soybean Entomology. Springer, NY.

McPherson, R. M., G. K. Douce and R. D. Hudson. 1993. Annual variation in stink bug (Heteroptera: Pentatomidae) seasonal abundance and species composition in Georgia soybean and its impact on yield and quality. J. Entomol. Sci. 28: 61-72.

McPherson, R. M., R. D. Hudson and D. C. Jones. 1996. Soybean Insects. Georgia Agric. Expt. Stn. Spec. Publ. 90: 37-38.

SAS Institute Inc. 1989. Sas user's guide: statistics, version 6 (4th ed.). SAS Institute Inc., Cary, NC.

Schon, M. K., and D. G. Blevins. 1989. Foliar boron applications increase the final number of branches and pods on branches of field-grown soybean. Plant Physiol. 92: 602-607.

Uniroyal Chemical. 1993. Dimilin 25W. Materials Safety Data Sheet. MSDS No. A340001.

Yanes, J., Jr. and D. J. Boethel. 1985. Evaluation of insecticides for control of soybean insect pests, 1984. Insecticide and Acaricide Tests: 1985. 10: 247.