Influence of Herbicide Tolerant Soybean Production Systems on Insect Pest Populations and Pest-Induced Crop Damage

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ABSTRACT Conventional soybean weed management and transgenic herbicide-tolerant management were examined to assess their effects on soybean insect pest populations in south Georgia in 1997 and 1998. Soybean variety had very little impact on the insect species observed, except that maturity group effects were observed for stink bug, primarily *Nezara viridula* (L.), population densities on some sampling dates. Stink bugs were more abundant on the early maturing varieties in mid-season. Velvetbean caterpillar, *Anticarsia gemmatalis* Hübner, potato leafhopper, *Empoasca fabae* (Harris), and grasshoppers *Melanoplus* spp. were more numerous on either conventional or herbicide-tolerant varieties on certain dates, although these differences were not consistent throughout the season. Soybean looper, *Pseudoplusia includens* (Walker), threecornered alfalfa hopper, *Spissistilus festinus* (Say), and whitefringed beetles, *Graphognathus* spp., demonstrated no varietal preference in this study. Few weed treatment differences were observed, but if present on certain sampling dates, then pest numbers were higher in plots where weeds were reduced (either postemergence herbicides or preplant herbicide plus postemergence herbicide). The exception to this weed treatment effect was grasshoppers, which were more numerous in weedy plots when differences were present. In postemergence herbicide plots, there were no differences in insect pest densities between the conventional herbicides (e.g., Classic, Select, Cobra, and Storm) compared with specific gene-inserted herbicide-tolerant materials (i.e., Roundup and Liberty). Defoliation, primarily by velvetbean caterpillar, was different between soybean varieties at some test sites but not different between herbicide treatments. We did not observe differences in seasonal abundance of arthropod pests between conventional and transgenic herbicide-tolerant soybean.

KEY WORDS *Nezara viridula*, *Anticarsia gemmatalis*, *Empoasca fabae*, *Spissistilus festinus*, genetically modified soybeans, Roundup Ready soybeans

WEEDS AND ARTHROPODS are the primary pest concern for Georgia soybean, *Glycine max* (L.), producers. Average herbicide costs in 1997 were $14.60/acre (range, of $5.25–$24.84) while insecticide costs plus field scouting for insect pests averaged $9.11/acre ($0.00–$18.14) (Givan 2000). In recent years, GA producers have adopted several management tactics that can improve production efficiency including varietal selection and reduced tillage (Raymer 2000), irrigation (McPherson et al. 1998), early soybean production system (McPherson et al. 2001), mid-season dimilin/boron treatments (McPherson and Gascho 1999), and herbicide-tolerant varieties (Raymer 2000).

Effectively managing weeds in Georgia soybeans is one of the most important crop protection decisions that growers face. Lack of effective weed control can result in greatly reduced yields (even abandoning the harvest of some fields), interference with the harvesting operation, and increased weed problems in subsequent years (Buckelew et al. 2000). Thus, nearly all of the soybean hectares in Georgia are treated with herbicides. Weed control, or lack thereof, interacts with the abundance of arthropods in the managed ecosystem. Norris and Kogan (2000) provide an excellent review of these interactions that can occur between weeds and arthropods. In soybeans, weed control has been reported to affect the abundance of several arthropod pests (Altieri and Todd 1981, Buntin et al. 1995, Lam and Pedigo 1998, Shelton and Edwards 1983) and predaceous insects (Zeiss and Klubertanz 1994). The recent release of transgenic soybeans that are tolerant to glyphosate, a highly effective broad-spectrum herbicide that controls many grass and broadleaf weeds, provides soybean producers with another effective and efficient weed management option.

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Table 1. Soybean varieties and weed management systems used in Decatur and Turner County test sites in 1997

Location (date planted)	Soybean variety	Weed management treatments[a] (amount of formulation per acre)	Cost[b] ($/acre)
Decatur Co. (26 June)	Benning-Conv.	1. None	0.00
	Hartz RR 244	2. Prowl 3.3 (2.4 pts.) PPI	7.89
		3a. Prowl PPI + Roundup 4 (1 qt.) Post-RR or	20.19
		3b. Prowl PPI + Classic 25 DF (0.5 oz) + Sufactant Post-Benning	16.34
		4a. Roundup 4 (1 qt.) Post only-RR or	14.62
		4b. Classic 25 DF (0.5 oz.) + Surfactant Post only-Benning	10.77
Turner Co. (10 June)	Benning-Conv.	1. None	0.00
	Hartz RR 244	2. Cultivation only	2.50
		3a. Roundup 4 (1 qt.) Post only-RR *or*	14.62
		3b. Classic 25 DF (0.5 oz) + Select 2 (8 oz) + Cobra 2 (6 oz.) + Agridex (1 qt) Post only-Benning	30.34
		4a. Cultivation + 3a (above)-RR *or*	17.12
		4b. Cultivation + 3b (above)-Benning	32.84

[a] Prowl-PPI applied three days before planting and incorporated with a rototiller in the upper 4″ of the soil. Post applications of Roundup, Classic, Select, and Cobra applied in late July to weeds in the 2–4 leaf stage. Cultivation at the Turner Co. site was made approximately 4 weeks after planting.

[b] Mean costs from 2000 Cooperative Extension Service surveys of herbicide prices in Georgia obtained from Lamar Zipper (Screven Co.) and Eric Prostko (Crop & Soil Sci. Dept, UGA, Tifton Campus), and include application costs of $2.32/a and cultivation costs of $2.50/a when utilized (Givan 2000).

Soybeans produced in Georgia, and throughout the southern region of the United States, are exposed to numerous insect pests, some of which cause annual economic damage to the crop (Funderburk et al. 1999). It is not clear whether the vast plantings of Roundup-Ready transgenic soybeans (Monsanto, St. Louis, MO), and also soybeans that are tolerant of other herbicides, will affect the seasonal abundance of any of these pests, or whether new pest species may emerge on these genetically altered soybeans. Initial investigations in Iowa (Buckelew et al. 2000) report that herbicide-resistant soybeans had very little impact on bean leaf beetle, *Cerotoma trifurcata* (Förster), potato leafhopper, *Empoasca fabae* (Harris), green cloverworm, *Hypena scabra* (F.), tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) and grasshopper, *Melanoplus* spp., populations. These insects are present on Georgia soybeans, but are considered minor pests (Hudson 1995). Instead, the stink bug complex, primarily *Nezara viridula* (L.), the velvetbean caterpillar, *Anticarsia gemmatalis* Hübner, and the soybean looper, *Pseudoplusia includens* (Walker) are economic pests in Georgia, and cause around $4 million in losses annually, because of costs of control and crop damage (Riley et al. 1997).

This study was conducted to examine the seasonal abundance and diversity of arthropod pests associated with herbicide-tolerant and conventional soybeans produced in south Georgia. The objectives of the research were to determine the effects of glyphosate-tolerant versus conventional herbicide systems on insect abundance, weed species and density, and insect-induced plant damage, and to incorporate these findings into the existing soybean Integrated Pest Management programs.

Materials and Methods

Field plots were established in 1997 and 1998 at five different test sites. In 1997, the two test locations included a double-cropped soybean field planted in wheat stubble after harvest in Turner County (south Central Georgia) and a conventionally plowed soybean field located at the Attapulgus Research Center in Decatur County (southwest Georgia). In 1998, all three test locations were in Tift County (south-central Georgia), at the ABAC farm, the Bowen farm, and the Lang Farm. The ABAC and Lang Farm sites were conventionally plowed and bedded. The Bowen Farm site was planted into a rye cover crop and weed management treatments included either conventional plowing of the land or strip-till planting into 10-cm rye stubble. The strip-till planting provided only a 30-cm cultivated band down the middle of the seed bed while the conventional planting had the entire seed bed cultivated.

Plots at each site were 24 rows wide by 15.1 m long, planted in rows with 91-cm row spacings and arranged in a randomized complete block design with four replications. Each plot was split with soybean variety being the main plot and weed treatment system the split plot, with individual split-plots being 6–8 rows wide by 15.1 m long. The planting dates, soybean varieties, weed management treatments, and costs of these treatments are presented in Table 1 (1997) and Table 2 (1998). At every test site there was at least one transgenic herbicide tolerant and one conventional soybean variety planted under 2–4 weed management systems. The herbicide tolerant soybean variety received a postemergence application of the herbicide to which it was tolerant (primarily Roundup glyphosate (Monsanto, St. Louis, MO), over-the-top of the Roundup Ready soybeans, but also Liberty glufosinate

Table 2. Soybean varieties and weed management systems used in Tift County test sites in 1998

Location (date planted)	Soybean variety	Weed management treatment[a] (amount of formulation per acre)	Cost[b] ($/acre)
ABAC Farm (4 June)	Benning-Conv	1. None	0.00
	Hartz 7550 RR	2. USA-1999 75 DF (9 oz.) PRE	13.32
		3a. USA-1999 + Roundup Ultra (1 qt) Post-RR	27.94
		3b. USA-1999 + Classic 25 DF (0.5 oz) + Kinetic (0.13% v/v) Post-Benning	22.09
		4a. Roundup Ultra (1 qt) Post-RR	14.62
		4b. Classic (0.5 oz) + Kinetic Post-Benning	12.20
Bowen Farm (2 June)	Benning-Conv	1a. Conv. tillage Prowl (1.2 qt) + Lexone 75 DF (0.33 lbs.) PRE + Classic (0.5 oz) + Kinetic (0.13% v/v) Post-Benning	22.83
	Hartz 7550 RR	1b. Conv. tillage Prowl (1.2 qt) PRE + Roundup Ultra (1 qt) Post-RR	22.33
		2a. Strip-till Roundup Ultra (1 qt) + Prowl (1.2 qt) + Lexone 75 DF (0.33 lbs.) + Kinetic PRE + Classic (0.5 oz) + Kinetic Post-Benning	36.74
		2b. Roundup Ultra (1 qt) + Prowl (1.2 qt.) + Kin. PRE + Roundup Ultra (1 qt) Post-RR	35.13
Lang Farm (2 June) or	Hertz 7550 RR	1. None	0.00
(*22 June)	Benning-Conv.	2. Prowl 3.3 (1 qt) + Vernam 7 (2.3 pts) PPI	25.49
	*Asgrow 2704 LL	3. Specific Post-emergence herbicides applied:	
	Asgrow 4501 STS	Hartz 7550-Roundup Ultra (1 qt.)	14.62
	RA 452-Conv.	Benning-Storm (1.5 pt) + Kinetic	15.95
		Asgrow 2704 LL-Liberty (1.5 pt.)	18.94
		Asgrow 4501 STS-Classic (0.66 oz)	10.17
		RA452-Storm (1.5 pt) + Kinetic	15.95

[a] USA 1999 75 DF is a premix of fluthiamide + metribuzin in a 2:1 ratio (Bayer Corp.). PRE represents preplant applications, PPI represents preplant and incorporated in the soil, postapplications were applied when weeds were in the 2–3 true leaf stage. Conventional tillage plots were cultivated prior to planting and again at 6 wk after planting. Strip-till plots had only a 12″ tilled band over the middle of the row at planting.
*Asgrow 2704 LL planted on 22 June.
[b] Mean costs from 2000 Cooperative Extension Service surveys of herbicide prices in Georgia obtained from Lamar Zipper (Screven Co.) and Eric Prostko (Crop & Soil Sci. Dept, UGA, Tifton Campus), and include application costs of $2.32/a and cultivation costs of $2.50/a when utilized (Givan 2000).

(Syngenta, Greensboro, NC), on the Liberty-linked soybeans at the Lang Farm in 1998). The sulfonylurea (DuPont Crop Protection, Wilmington, DE) tolerant soybean (STS) variety Asgrow 4501 STS (Monsanto) was not treated with a postemergence application of Synchrony trifensulfuron herbicide (DuPont Crop Protection) at the Lang Farm test in 1998 because it was not available. Therefore, these plots were treated with a standard postemergence application of Classic chlorimuron herbicide (DuPont Crop Protection). All the conventional soybean varieties (without transgenic herbicide tolerance) were treated with conventional postemergence herbicides, as recorded in Tables 1 and 2. All tests included a nonherbicide treatment and either a preplant incorporated (PPI) or preemergence treatment, except at the Bowen Farm in 1998, as additional weed management treatments that were compared between soybean varieties. The foliar preemergence and postemergence herbicide applications were delivered through a tractor mounted sprayer calibrated to deliver 187L per ha at 40 psi and the preplant incorporate treatments were applied with a tractor mounted power-tiller delivering 223L per ha at 40 psi according to University of Georgia Extension Service guidelines (Raymer 2000).

When soybean plants reached a height of ≈12 cm and V6 growth stage, and continuing until plant maturity growth stage R7 (Fehr et al. 1971), a 25-sweep sample was taken from a single row from each plot using a 38-cm diameter sweep net (Kogan and Pitre 1980). Each sample was bagged, returned to the laboratory, frozen, and the arthropods counted at a later date. All commonly observed arthropods in each sample were recorded. On the last sampling date, plots were visually rated for percent defoliation. The entire plot was examined in two row increments for the amount of foliage removed. An estimate of percent defoliation, in increments of 5%, was obtained for each two-row sample and a mean percentage was determined per plot.

Weed population densities were measured in each plot in late August, when the soybean growth stage was late R5 (pods filling with seeds) or R6 (full sized seeds in the pods) (Fehr et al. 1971), by counting all weeds present in a random m^2 quadrat. In some tests, weed biomass (kg/m^2) and weight (gm/plant) also were obtained.

Insect population data (by date), percent defoliation, and weed measurements were analyzed for varietal and weed management effects by using an analysis of variance (ANOVA) PROC GLM procedure of SAS with a split-plot model (SAS Institute 1990). Defoliation percentages were first transformed using the angular transformation (arcsine of the square root of x) before analysis. Treatment means were separated using the Tukey mean comparison test ($P = 0.05$). Specimens of the insect pests reported in this study are

Table 3. Abundance of southern green stink bugs and total stink bugs (SEM) in a Roundup-Ready (Hartz RR) and conventional soybean varieties with different weed treatment regimes, Decatur and Tift County, Georgia, 1997–1998

Variety and weed treat[a]	Southern green stink bugs/25 sweeps[b]					
	5 Aug	12 Aug	19 Aug	26 Aug	9 Sept	16 Sept
	Decatur County 1997					
1. None	2.3 (1.1)b	0.2 (0.1)b	2.5 (1.0)a	2.5 (1.8)a	—	—
2. PPI	1.8 (0.8)b	1.0 (0.3)b	1.5 (0.7)a	0.5 (0.3)a	—	—
3. PPI & Post	1.0 (0.7)b	5.8 (2.3)a	3.5 (1.3)a	0.2 (0.2)a	4.8 (2.2)a	26.5 (12.1)a
4. Post	5.3 (1.8)a	4.8 (1.8)a	3.5 (1.5)a	1.5 (0.8)a	6.5 (3.4)a	27.1 (10.8)a
Hartz RR 244	2.0 (1.6)a	3.0 (1.4)a	1.6 (1.1)b	0.8 (0.4)a	7.0 (4.1)a	36.3 (14.1)a
Benning	3.2 (2.0)a	2.9 (1.7)a	3.9 (1.0)a	1.6 (0.6)a	4.3 (3.0)a	17.3 (8.8)b
	Tift County (Lang Farm) 1998					
	Southern green stink bugs/25 sweeps			Total stink bugs/25 sweeps		
	19 Aug	26 Aug	2 Sept.	19 Aug.	26 Aug.	2 Sept.
1. None	0.6 (0.4)a	2.4 (0.9)b	2.3 (1.8)a	1.1 (0.9)a	2.7 (1.0)b	3.7 (2.8)a
2. PPI	0.7 (0.3)a	3.2 (2.0)ab	3.3 (2.3)a	1.5 (1.0)a	5.1 (1.3)a	4.9 (2.9)a
3. Post	0.6 (0.3)a	4.6 (1.3)a	2.1 (1.5)a	1.1 (0.8)a	5.9 (2.0)a	3.7 (3.2)a
H7550RR	0.0 (0.0)b	1.9 (0.8)ab	0.9 (0.7)c	0.3 (0.2)b	2.1 (1.4)b	1.4 (0.8)b
Benning	0.2 (0.1)b	0.2 (0.2)b	0.8 (0.7)c	0.6 (0.3)b	0.3 (0.3)b	2.3 (1.1)b
A2704 LL	0.2 (0.1)b	5.3 (2.8)a	4.0 (2.1)ab	0.6 (0.3)b	7.0 (3.2)a	5.2 (3.3)ab
A4501STS	1.3 (0.5)a	5.3 (2.5)a	2.3 (1.8)abc	1.9 (1.0)a	6.7 (3.0)a	4.4 (3.0)ab
RA 452	1.4 (0.7)a	4.2 (2.5)a	4.7 (2.2)a	2.6 (1.6)a	6.5 (2.9)a	6.9 (4.5)a

[a] See Tables 1 and 2 for specific weed management treatments.

[b] The dates reported for southern green stink bugs and total stink bugs (so. green, green, and brown) are the only dates with either a variety or weed treatment difference for these pests. Column means for variety or weed treatment followed by the same letter are not significantly different (Tukey test, $P = 0.05$).

deposited in the University of Georgia Arthropod Collection.

Results and Discussion

Stink Bugs. Stink bugs, primarily southern green stink bug, *N. viridula,* were present at all five test sites, and had sufficient population densities at two test locations to detect weed treatment and varietal differences. In Decatur County on 5 August, there were higher southern green stink bug numbers in the postemergence weed treatment four (Roundup in the Roundup-Ready variety and Classic in the conventional variety) than in the other weed treatments (Table 3). On 12 August, higher stink bug densities were present in both the postemergence (Trt. 4) and preplant incorporated plus postemergence (Trt. 3) weed treatments than in the plots that received either no herbicides or just a preplant incorporated herbicide (Table 3). Only two sampling dates had varietal differences in southern green stink bug populations, on 19 August, when stink bugs were more abundant on Benning (3.9 ± 1.7 per sweeps) than on Hartz RR-244 (1.6 ± 1.1) and 16 September when numbers were higher on Hartz RR-244 (36.3 ± 14.1) than on Benning (17.3 ± 8.8). Stink bug populations were similar in the postemergence herbicide plots, whether treated with Roundup or Classic, on all sampling dates, even the dates when stink bug numbers exceeded the economic threshold level of three per 25 sweeps (Jones and McPherson 2002). On two dates (5 and 12 August) the stink bug numbers were higher in the postemergence treatments (Roundup or Classic) than in the no herbicide and preplant treatments (Table 3).

At the Tift County Lang Farm site, southern green and total stink bugs (southern green, green, and brown stink bugs combined) were more abundant on the earlier maturing Asgrow 2704 LL (Maturity group 2), Asgrow 4501 STS (Maturity group 4), and RingAround 452 (Maturity group 4) than on the two Maturity group 7 varieties (Hartz 7550 RR and Benning) on several dates in late August and early September (Table 3). Stink bug population densities exceeded the economic threshold of three per 25 sweeps on several dates at this test site. Observing higher densities in the early maturing varieties is consistent with previous reports that stink bugs are attracted to earlier maturing soybean varieties (McPherson and McPherson 2000). The herbicide treatments had little effect on stink bug population densities; however, on 26 August there were higher numbers of southern green stink bugs and total stink bugs in the postemergence herbicide plots than in the no herbicide plots (Table 3).

Velvetbean Caterpillars. Velvetbean caterpillar populations were present at relatively high levels at all five test locations in this study. In Decatur County in 1997, herbicide treatment had very little effect on the velvetbean caterpillar densities (Table 4). There was a significant weed treatment effect on 12 August. The postemergence treatment (9.3 ± 2.8 per 25 sweeps) and the preplant incorporated plus postemergence treatment (10.0 ± 3.1) had higher populations than in the no herbicide (1.0 ± 0.4) or preplant incorporated only herbicide plots (1.3 ± 0.7). Differences in velvetbean caterpillar populations in the postemergence weed treatments of either Roundup or Classic were not significant. Caterpillar populations differed significantly among varieties on 19 and 26 August, and on 9 September, with higher densities on the Hartz RR244 variety than on Benning. Defoliation was significantly higher in the Hartz RR244 (79.8% ± 6.3%)

Table 4. Abundance of velvetbean caterpillars and percentage defoliation (SEM) in a Roundup-Ready (Hartz RR) and conventional soybean varities with different weed treatment regimes, Decatur and Tift County, Georgia, 1997–1998

Variety and weed treat[a]	Velvetbean caterpillars/25 sweeps (SEM)[bc]					% defol.
	12 Aug	19 Aug	26 Aug	9 Sept	16 Sept	
	Decatur County 1997					
1. None	1.0 (0.4)b	8.0 (3.1)a	8.3 (4.2)a	—	—	—
2. PPI	1.3 (0.7)b	11.8 (3.8)a	10.5 (4.1)a	—	—	—
3. PPI & Post	10.0 (3.1)a	8.3 (4.0)a	16.0 (6.6)a	37.0 (28.2)a	10.5 (6.4)a	59.8 (6.1)a
4. Post	9.3 (2.8)a	8.0 (2.5)a	16.3 (6.3)a	59.8 (30.3)a	9.8 (4.1)a	67.1 (6.0)a
Hartz RR 244	5.9 (2.1)a	13.3 (4.1)a	17.6 (6.7)a	75.5 (30.8)a	12.3 (8.4)a	79.8 (6.3)a
Benning	4.9 (2.0)a	4.8 (3.3)b	7.9 (2.5)b	21.3 (17.3)b	8.0 (3.8)a	47.1 (5.1)b
	Tift County (Lang Farm) 1998					
	20 July	28 July	19 Aug	26 Aug	17 Sept.	% defol.
1. None	2.1 (1.0)b	5.0 (2.0)b	21.8 (11.3)ab	9.0 (4.0)a	29.8 (15.3)a	27.1 (3.1)a
2. PPI	2.4 (0.6)b	5.3 (1.8)b	19.1 (12.4)b	11.8 (4.8)a	35.3 (18.9)a	30.2 (3.3)a
3. Post	4.3 (1.2)a	9.1 (2.0)a	34.4 (20.2)a	13.3 (6.6)a	24.4 (14.5)a	28.0 (2.9)a
H7550 RR	3.6 (2.3)a	4.7 (4.5)ab	21.0 (12.5)a	6.0 (4.3)c	32.7 (19.3)a	44.2 (4.7)a
Benning	3.8 (2.8)a	10.0 (6.3)a	22.0 (9.8)a	7.1 (3.3)c	28.8 (16.1)a	40.0 (3.8)a
A2704 LL	0.5 (0.4)b	0.0 (0.0)b	21.9 (10.3)a	9.9 (2.7)bc	—	16.8 (2.1)b
A4501STS	2.8 (2.0)ab	9.5 (5.5)a	30.6 (16.8)a	17.9 (5.2)a	—	16.9 (2.3)b
RA 452	3.9 (3.0)a	10.5 (6.1)a	29.9 (16.1)a	15.8 (5.3)ab	—	14.3 (1.8)b

[a] See Tables 1 and 2 for specific weed management treatments.
[b] Only dates with significant differences or population peaks included. Column means for herbicide treatment or variety followed by the same letter are not significantly different (Tukey test, $P = 0.05$).
[c] Sweep samples in September and percentage defoliation were not obtained in weed treatments 1 and 2 because of severe sicklepod infestations that overtook the entire plot.

than in the Benning (47.1 ± 5.1%) but not different between herbicide treatments. The high level of defoliation in the Hartz variety is not surprising since the economic threshold of 40 per 25 sweeps (Jones and McPherson 2002) was exceeded on 9 September (Table 4).

Velvetbean caterpillar populations at the Lang Farm site in 1998 were significantly different between varieties and herbicide treatments on some dates (Table 4). In July, there were lower populations on Asgrow 2704 LL than the other varieties. This difference was probably due in part to the later planting date for A2704 LL (22 June, because the seeds were late arriving) compared with the other varieties (2 June). On 26 August, velvetbean caterpillars were more abundant on Asgrow 4501 STS (17.9 ± 5.2) than on the other varieties except RA 452 (15.8 ± 5.3). On the three sampling dates with significant weed treatment effects, the plots treated with a postemergence herbicide had higher caterpillar population densities. Within the postemergence herbicide plots, caterpillar populations were similar between Roundup, Storm, Liberty, and Classic treatments, with no variety by weed treatment interactions on any sampling date. The percent defoliation was higher in the later maturing Hartz 7550 RR (44.2 ± 4.7) and Benning (40.0 ± 3.8%) plots than in the other varieties, because of a second population peak of velvetbean caterpillars on 17 September (Table 4). The 40% defoliation in these varieties was not surprising given that the economic threshold of 40 caterpillars per 25 sweeps was approached in mid-September. The other three varieties (A 2704 LL, A 4501 STS, and RA 452) were already maturing by early September and not attractive to velvetbean caterpillars.

There were higher populations of velvetbean caterpillars on the postemergence herbicide plots (1.5 ± 0.8) and postemergence + cultivation (2.6 ± 1.3) than in the no herbicide (0.3 ± 0.1) and cultivation only plots (0.3 ± 0.2) on 1 October at the Turner County site in 1997 (Table 5). This was the only date where a weed treatment difference was detected. On 12 Sep-

Table 5. Abundance of velvetbean caterpillars and percent defoliation (SEM) in a Roundup-Ready (Hartz RR) and conventional (Benning) soybean variety with different weed treatment regimes, Turner and Tift County, Georgia, 1997–1998

Variety and weed treat.[a]	Velvetbean caterpillars/25 sweeps		% Defoliation
	12 Sept	1 Oct	
	Turner County 1997		
1. None	6.2 (3.7)a	0.3 (0.1)b	7.8 (3.1)a
2. Cultivation	5.1 (3.0)a	0.3 (0.2)b	10.6 (3.5)a
3. Post	6.7 (2.8)a	1.5 (0.8)a	10.9 (2.9)a
4. Cult. & Post	6.9 (2.2)a	2.6 (1.3)a	11.9 (3.3)a
Hartz RR 244	4.1 (2.1)b	1.4 (0.7)a	10.5 (3.4)a
Benning	8.3 (2.3)a	0.9 (0.6)a	10.1 (3.3)a
	Tift County (ABAC Farm) 1998		
	20 Aug	31 Aug	% Defoliation
1. None	6.4 (3.3)b	19.8 (8.2)b	20.7 (3.0)b
2. PRE	13.4 (3.6)a	28.6 (7.4)ab	25.1 (4.1)ab
3. PRE & Post	10.0 (5.1)ab	25.2 (8.6)ab	27.8 (3.9)a
4. Post	14.8 (4.0)a	35.4 (7.1)a	30.7 (5.8)a
Benning	16.6 (7.4)a	30.6 (7.8)a	29.4 (4.0)a
Hartz 7550 RR	5.6 (3.1)b	23.9 (7.1)a	22.7 (2.1)a
	Tift County (Bowen Farm) 1998		
	24 Aug.	31 Aug.	% Defoliation
Conventional	18.3 (9.5)a	13.9 (6.1)a	14.4 (3.4)a
Strip-till	14.8 (8.3)a	13.3 (6.4)a	8.8 (2.0)b
Benning	17.7 (8.8)a	13.8 (6.7)a	12.3 (2.3)a
Hartz 7550 RR	15.4 (7.8)a	13.4 (6.0)a	10.9 (2.1)a

[a] See Tables 1 and 2 for specific weed management treatments.
[b] Only dates with significant differences or population peaks included. Column means for treatment or variety followed by the same letter are not significantly different (Tukey Test, $P = 0.05$).

Table 6. Abundance of threecornered alfalfa hoppers (SEM) in a Roundup Ready (Hartz 7550RR) and conventional soybean varieties with different weed treatment regimes, Turner and Tift County, Georgia 1997–1998

Variety and weed treat.[a]	Hoppers per 25 sweeps[b]			Variety and weed treat.[a]	Hoppers per 25 sweeps[b]	
	10 Aug	26 Aug	2 Sept.		8 Aug	28 Aug
Tift County (Lang Farm) 1998				Turner County 1997		
1. None	0.0 (0.0)a	1.0 (0.8)a	1.5 (0.7)a	1. None	1.2 (0.4)a	1.8 (0.7)a
2. PPI	0.3 (0.3)a	0.9 (0.6)a	1.4 (0.5)a	2. Cult. only	1.4 (0.6)a	1.4 (0.5)a
3. Post	0.3 (0.2)a	1.0 (0.6)a	1.7 (0.7)a	3. Post only	0.4 (0.2)b	2.3 (1.1)a
				4. Cult & Post	0.8 (0.4)ab	1.2 (0.7)a
H7550 RR	0.7 (0.3)a	1.9 (0.6)a	1.7 (0.6)ab			
Benning	0.0 (0.0)b	0.5 (0.2)bc	2.3 (0.9)a	Hartz RR 244	0.9 (0.4)a	2.1 (0.5)a
A2704 LL	0.3 (0.3)ab	0.8 (0.3)bc	1.0 (0.3)b	Benning	1.0 (0.6)a	1.2 (0.3)b
A4501STS	0.0 (0.0)b	1.3 (0.7)ab	1.3 (0.7)ab			
RA 452	0.5 (0.2)ab	0.3 (0.2)c	1.1 (0.3)b			

[a] See Tables 1 and 2 for specific weed management treatments.

The dates reported for threecornered alfalfa hoppers are the only dates with either a variety or weed treatment difference for this pests. Column means for variety or weed treatment followed by the same letter are not significantly different (Tukey test, $P = 0.05$).

tember, there were more caterpillars on Benning (8.3 ± 2.3) than on Hartz RR (4.1 ± 2.1), but this was the only time during the season that a varietal difference was detected. The percent defoliation was not different between varieties or herbicide treatments (Table 5).

Velvetbean caterpillars were significantly different between varieties and weed management systems on some dates at the ABAC test site in 1998 (Table 5). Velvetbean caterpillars were more abundant on Benning soybeans (16.6 ± 7.4) than on Hartz 7550 RR soybeans (5.6 ± 3.1) on 20 Aug, the only date where a varietal difference was observed. On 20 and 31 August there were weed treatment differences, with more velvetbean caterpillars on treatment four (postemergence herbicide only) than on treatment one (no herbicide applied) but there was a significant variety by weed treatment interaction on both of these dates (Table 5). The percentage defoliation also was higher in treatments three and four than in treatment one at the ABAC test site but not different between the conventional and herbicide-tolerant varieties (Table 5).

No differences were observed for velvetbean caterpillar populations at the Bowen Farm test site in 1998, not even at the population peaks on 24 and 31 August (Table 5). Percent defoliation was higher on the conventionally tilled plots than on the strip-till plots at the Bowen Farm site (Table 5), although defoliation levels were below the defoliation threshold of 30% (Raymer 2000) in all plots. No differences in defoliation were present between the conventional (Benning) and herbicide-tolerant (Hartz RR 7550) varieties (Table 5).

Threecornered Alfalfa Hoppers. Threecornered alfalfa hoppers were commonly observed at all five test sites, but significant weed treatment or varietal differences were detected at only two sites. In Turner County in 1997, hoppers were significantly more abundant on Hartz RR 244 (2.1 ± 0.5) than on Benning (1.2 ± 0.3) on 28 August, and more numerous in the no herbicide (1.2 ± 0.4) and cultivation only plots (1.4 ± 0.6) than in the postemergence plots (0.4 ± 0.2) on 8 August (Table 6). Threecornered alfalfa hoppers were more numerous on some varieties on certain sampling dates at the Lang Farm site in 1998, but there was no clear trend for a herbicide tolerant or conventional variety (Table 6). No weed treatment effects were noted on any sampling date at the Lang Farm test site (Table 6).

Soybean Loopers. Soybean looper populations were relatively low at all test sites on all sampling dates. However, at the Decatur County site in 1997 there was a significant difference in looper densities between the four weed treatments on 12 August. On this date, there were more loopers per 25 sweeps in the plots treated with a postemergence herbicide (2.8 ± 1.4) than in the PPI only (0.5 ± 0.3) and no herbicide treatments (0.3 ± 0.2) while the PPI plus postemergence herbicide (1.0 ± 0.5) was not different. However, looper densities in the Roundup postemergence plots were similar to densities in the Classic postemergence plots on all sampling dates.

Other Arthropod Pests. Potato leafhoppers were observed at two test locations. They were more abundant on Benning than on Hartz 7550 RR on 13 and 20 August (16.9 versus 11.0 and 9.6 versus 5.9, respectively) at the ABAC test site in 1998 (Table 7). Leafhoppers also were more numerous on treatment four (post emergence herbicide only) on 20 August; however, a significant variety by treatment interaction was present on this date (Table 7).

There also were differences in potato leafhoppers numbers on four and 13 August at the Bowen Farm site in 1998, with more leafhoppers on the Benning soybeans on the earlier date and higher densities on the Hartz 7550 RR on the later date (Table 7). No differences were detected between the weed treatments on any date at this test site (Table 7).

Grasshoppers, primarily *Melanoplus femurrubrum* (DeGeer) and *M. differentialis* (Thomas), were abundant at one test site. They were more numerous in Hartz 7550 RR and Asgrow 2704 LL varieties on some sampling dates at the Lang Farm test site in 1998, but there was no clear trend for preference for a herbicide tolerant or conventional variety (Table 7). The no herbicide plots did have more grasshoppers on 26

Table 7. Abundance of potato leafhoppers, and grasshoppers per 25 sweeps (SEM) in a Roundup-Ready (Hartz 7550 RR) and conventional soybean varieties with different weed treatment regimes, Tift County, GA, 1998

Variety and weed treat.[a]	Potato leafhoppers		Variety and weed treat[a]	Potato leafhoppers		Variety and weed treat[a]	Grasshoppers		
	13 Aug	20 Aug		4 Aug	13 Aug		19 Aug	26 Aug	2 Sept.
Tift County (ABAC) 1998			Tift County (Bowen Farm) 1998			Tift County (Lang Farm) 1998			
1. None	12.5 (4.9)a	6.9 (2.2)b	Conventional	19.3 (9.7)a	9.4 (4.1)a	1. None	4.0 (2.8)a	9.3 (4.1)a	3.2 (2.4)a
2. PRE	14.7 (5.3)a	5.8 (2.0)b	Strip-till	20.0 (10.3)a	14.4 (6.5)a	2. PPI	2.2 (1.1)a	6.4 (3.8)ab	6.1 (3.3)a
3. PRE & Post	9.9 (5.5)a	6.7 (2.3)b				3. Post	1.5 (1.0)a	3.7 (1.4)b	3.5 (2.0)a
4. Post	18.8 (8.1)a	11.6 (2.4)a							
Benning	16.9 (4.1)a	9.6 (2.0)a	Benning	23.2 (3.6)a	8.2 (2.2)b	H7550 RR	6.9 (3.1)a	2.6 (1.9)b	8.8 (5.1)a
H7550 RR	11.0 (3.0)b	5.9 (1.8)b	H7550 RR	16.2 (3.3)b	15.7 (5.2)a	Benning	1.1 (0.9)b	2.3 (1.8)b	3.4 (2.7)ab
						A2704 LL	1.3 (1.0)b	19.6 (9.8)a	3.3 (2.0)ab
						A4501STS	2.5 (1.2)b	2.5 (2.b	4.0 (3.0)ab
						RA 452	1.0 (0.7)b	5.3 (4.5)ab	1.6 (1.2)b

[a] See Table 2 for specific weed management treatments.
[b] The dates reported are the only dates with either a variety or weed treatment difference for these pests. Column means for variety or weed treatment followed by the same letter are not significantly different (Tukey test, $P = 0.05$).

August than the plots treated with a postemergence herbicide, but that was the only date on which there was a difference in grasshopper densities between weed treatments (Table 7).

There were more whitefringed beetles, *Graphognathus* spp., per 25 sweeps in the postemergence herbicide plots (2.2 ± 1.0) and preemergence plus postemergence plots (1.8 ± 0.7) than in the preemergence only plots (0.5 ± 0.2) and no herbicide plots (0.7 ± 0.3) on 12 September at the Tift County ABAC test site in 1998. No differences were detected between the conventional and herbicide-tolerant varieties for whitefringed beetles on any sampling date. The ABAC location was the only test site where whitefringed beetle infestations were observed.

Weed Density. The most common weed species (and their densities) at the Turner County site in 1997 were yellow nutsedge, *Cyperus* spp. (21.0/m^2), johnsongrass, *Sorghum halepense* (L.) Pers. (1.1/m^2), sicklepod, *Senna obtusifolia* (L.) Irwin & Barneby (5.5/m^2), and Florida pusley, *Richardia scabra* L., (4.5/m^2). Weeds were uniformly distributed between the conventional and herbicide-tolerant varieties. Significantly lower densities of weed species were present in the postemergence herbicide plots. There was no interaction between variety and weed treatment for weed abundance. Both Roundup used with the Roundup Ready variety and the conventional tank mix of herbicides used with the conventional variety were effective in reducing the weed densities at the Turner County Site. The herbicide treatment costs ranged from $14.62/acre to $32.84/acre at the Turner Co. site (Table 1). Although the weed treatment costs varied greatly at this test site, weed suppression was similar between the postemergence treatments applied.

Sicklepod was very abundant at the Decatur County 1997 test site. In fact, by early September, the plots that received no postemergence herbicides (treatments one and two) could no longer be sampled with a sweep net because the sicklepod was over 2 m high and had completely taken over the soybean plots. Weed treatments one and two had significantly more sicklepod biomass, density and weight than the treatments receiving postemergence applications of either Roundup or Classic (Table 8). The Benning soybean variety had significantly taller and heavier sicklepod plants than in Hartz RR-244, but sicklepod biomass and density were not different between the two varieties (Table 8). The herbicide treatment costs ranged from $7.89/acre to $20.19/acre at the Decatur Co. test site (Table 1); however, the no herbicide treatment ($0.00 cost) and the Prowl PPI only ($7.89/acre) were completely ineffective in controlling weeds in both the conventional and herbicide-tolerant plots.

Weed density at the ABAC farm site in 1998 was comprised of yellow nutsedge, sicklepod, FL beggerweed, *Desmodium tortuosum* (Swartz) deCandolle, Palmer amaranth, *Amaranthus palmeri* S. Wats., and Texas panicum, *Panicum texanum* Buckl. There were no varietal differences in weed populations. All the pre- and postemergence weed treatments had lower weed densities than in the untreated. There were no significant variety by weed treatment interactions, indicating that the Roundup and the conventional herbicides were both effective in reducing weeds, although the herbicide treatment costs ranged from $12.20/acre to $27.94/acre at the ABAC Farm test site (Table 2).

Table 8. Biomass, density, and weight (SEM) of sicklepod weed infestation in a Roundup Ready (Hartz RR) and conventional (Benning) soybean variety with four different weed treatment regimes, Decatur County, Georgia, 1997

Variety and weed treat.[a]	Biomass (kg/m^2)[b]	Density (#/m^2)[b]	Plant Biomass (g/plant)[b]
1. None	1.62 (0.83)a	22.2 (4.0)a	88.1 (11.3)a
2. PPI only	1.45 (0.77)a	24.9 (6.6)a	87.9 (10.8)a
3. PPI + Post	0.20 (0.15)b	12.1 (6.0)b	17.2 (13.3)b
4. Post only	0.20 (0.11)b	7.0 (5.5)b	53.3 (23.5)b
Hartz RR 244	0.90 (0.63)a	18.9 (9.9)a	38.1 (20.3)b
Benning	0.80 (0.57)a	13.1 (7.0)a	86.2 (27.1)a

[a] See Table 1 for specific weed management treatments 1–4.
[b] Column means for herbicide treatment or variety followed by the same letter are not significantly different (Tukey Test, $P = 0.05$). Samples obtained in late August.

At the Bowen Farm site in 1998, the most common weed species were yellow nutsedge, TX panicum, southern crabgrass, *Digitaria ciliaris* (Retz.) Koel. and Florida beggerweed. Benning and Hartz 7550 RR had similar weed densities and there were no variety by weed treatment interactions. Both the conventional herbicide treatment and Roundup treatment were effective in reducing weed pests. The herbicide treatment costs at this test site ranged from $22.33/acre to $36.74/acre (Table 2).

The most common weed species at the Lang Farm site in 1998 were Florida beggerweed, TX panicum, Palmer amaranth, and common Bermuda grass, *Cynodon dactylon* (L.) Persoon. These weeds were uniformly distributed between the five varieties. Significantly lower weed densities were present in the preplant and postemergence herbicide plots, but there were no differences between the herbicide treatments and no interaction between variety and weed treatment. The herbicide treatment costs at the Lang Farm site ranged from $10.17/acre to $25.49/acre (Table 2).

Conclusions

There were very few differences in insect pest population densities between conventional and herbicide-tolerant soybean varieties examined in this study. Varietal differences in stink bug populations that approached economic threshold were associated with soybean maturity grouping on some dates, with higher populations in the earlier maturing varieties on the mid-season sampling dates. However, differences were not associated with gene insertation for herbicide tolerance (Roundup glyphosate at all five sites, and Liberty glufosinate at one site). The other insect pest that attained economic threshold population levels during this study was the velvetbean caterpillar. A few varietal differences were noted on some sampling dates but no trends were established for varietal preference. On three dates at the Decatur County site in 1997, velvetbean caterpillars were more abundant on the Roundup Ready variety than on the conventional variety. However, at the Turner County site in 1997, the opposite varietal response (more numerous on conventional soybeans) was observed on one date. In 1998, velvetbean caterpillars were more numerous on the conventional variety on one date at the ABAC site, no differences between varieties on any date at the Bowen Farm site, and no differences between conventional and herbicide tolerant varieties within the same maturity group at the Lang Farm site. Potato leafhoppers were more numerous on the conventional soybean than on Roundup Ready soybeans on two dates at the 1998 ABAC site and one date at the 1998 Bowen Farm site, but also more abundant on the Roundup Ready variety on one date at the 1998 Bowen Farm site.

Very few weed management differences in arthropod populations were observed within the five test sites being evaluated in the study. When herbicide treatment differences were present, it was primarily because of higher numbers of stink bugs, velvetbean caterpillars, soybean loopers, whitefringed beetles, and potato leafhoppers in plots where weed densities were reduced (treated with a postemergence herbicide only, or a postemergence herbicide plus a preplant herbicide). However, grasshoppers were more numerous in the weedy plots (no herbicides applied) when a weed treatment difference was noted. In all the postemergence plots that were evaluated, there were no differences in insect populations between the conventional postemergence materials (e.g., Classic, Select, Cobra, and Storm) and the specific gene-inserted herbicide-tolerant materials (i.e., Roundup and Liberty). Thus, it appears that these transgenic varieties, and the specific herbicides applied to these herbicide-tolerant varieties, do not adversely affect the seasonal soybean arthropod infestations. However, the overall weed management systems (preplant, postemergence, and cultivation) and resulting weed infestations can influence certain insect pests periodically during the growing season irrespective of whether conventional or herbicide tolerant soybean varieties are planted.

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