Pest Insects and Natural Enemies in Transitional Organic Cotton in Georgia[1]

Glynn Tillman,[2] Marshall Lamb,[3] and Benjamin Mullinix, Jr.[4]

USDA-ARS, Crop Protection and Management Research Laboratory, Tifton, Georgia 31793 USA

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Abstract This research was conducted in experimental plots in Georgia from 2004 through 2006 and assessed the prospects for transitioning to a totally organic management system for cotton. The seasonal abundance of insect pests and their natural enemies over the 3-yr transitional period are reported herein. The heliothines, *Heliothis virescens* (F.) and *Helicoverpa zea* (Boddie), and stink bugs, mainly *Nezara viridula* (L.), *Euschistus servus* (Say), and *Euschistus quadrator* (Rolston), were the 2 groups of insect pests found on cotton. Heliothine larvae were observed each year of the study but, in general, infestations of heliothines were higher in 2004 than in the other 2 yrs. Stink bugs were observed in relatively high numbers, and the percent of cotton bolls damaged by these pests was high only during year 2 of the study. Over the 3-yr period, the red imported fire ant, *Solenopsis invicta* Buren, various spiders, including *Oxyopes scalaris* Hentz and *Peucetia viridans* (Hentz), the big-eyed bug, *Geocoris punctipes* (Say), and the pirate bug, *Orius insidiosus* (Say), were the most abundant predators of the heliothines and stink bugs. The endoparasitoid *Toxoneuron nigriceps* Viereck and an ascovirus also contributed to larval mortality of *H. virescens*. The endoparasitoid *Trichopoda pennipes* (F.) parasitized adults of *N. viridula*.

Key Words organic cotton, insect pests, natural enemies

America's appetite for organically-grown products has increased at approximately 20% per year for the last 10 yrs (Dimitri and Greene 2002). This indicates that organic agriculture is one of the fastest growing sectors of the U.S. agricultural economy. The demand for organically-grown foods and other products is increasing due to consumer concern over food safety and the environment. If growers wish to convert to organic production, they must do so within a 3-yr period under the USDA National Organic Program Standard, and throughout this period, only compounds certified for use in organic production can be used for management of insects. These issues along with some problems encountered during transitioning from conventional to organic production deter small farmers from adopting this practice. Consequently, the overall goal for the research reported herein was to determine the prospects for transitioning to a totally organic management system for cotton in experimental plots in Georgia from 2004 through 2006. This is a report on the seasonal abundance of insect pests and their natural enemies over the 3-yr transitional period. An economic

[1]Received 16 May 2008; accepted for publication 17 July 2008.
[2]Address inquiries (email: Glynn.Tillman@ars.usda.gov).
[3]USDA-ARS, National Peanut Research Laboratory, Dawson, GA 39842.
[4]Texas A&M University, Lubbock, TX 79499.

analysis of all aspects of production, including insect pest management and cotton yields, will be reported in a subsequent paper.

Materials and Methods

Experimental plots. The 3-yr transitional organic study was initiated in the fall of 2003 and ended in the fall of 2006 and was conducted at the USDA-ARS research farm located in Shellman, GA. Two irrigation treatments were a drip irrigation system (pivot system unavailable) and no irrigation. The 2 irrigation treatments were replicated 2 times within the crop. In 2004 and 2005, the plot size for each treatment replicate was 10.1 × 30.5 m. In 2006, plot size for each treatment replicate was 8.2 × 30.5 m. Plot size was kept relatively small in part because intensive hand-labor was required for weed control. Nontransgenic varieties of cotton were used. Delta Pine 491 cotton was planted on 11 May 2004. Fiber Max 966 cotton was planted on 17 May 2005 and 2 May 2006. These varieties of cotton were chosen because each produces extrafloral nectar which can be a food source for parasitic wasps (Röse et al. 2006). In 2005 and 2006, cotton seeds were treated with *Bacillus subtilis* GB03 (Kodiak [59 ml per 100 seed], Trace Chemicals, LLC, Pekin, IL) before planting for control of soil pathogens.

Cover crops can help reduce production costs through improved soil water relationships and long-term soil productivity, increased habitat for beneficial insects, and greater agroecosystem stability (Reeves 1994). Therefore, in the fall of 2003 and 2004, a cover crop was planted in these plots. In 2003, oats were planted as a cover crop on 26 December. In 2004, a 1:1 mixture of rye:crimson clover was planted as a cover crop on 8 December. A cover crop was not planted the third year of the study so that mainly conventional tillage practices could be used for weed control. Weeds also were controlled by hand-hoeing and burning using a flame torch. Composted poultry litter (840 kg per ha in 2004, Perdue Agrirecycle, LLC, Seaford, DE) or pelletized poultry litter (Microstart60 [2380 kg per ha in 2005 and 560 kg per ha in 2006], Perdue Agrirecycle, LLC, Seaford, DE) was used as a fertilizer for the cotton crops.

Insects. Above-ground pest insects and their natural enemies were monitored weekly for 10 wks in 2004 and 2006 and for 9 wks in 2005. Each sampled cotton plant was thoroughly searched for insect pests and natural enemies, and a single cotton boll, if present on the plant, was checked for stink bug damage. Drop sampling was also used to determine the number of stink bugs within 1.82-m of cotton row. In 2004, 2 plant and drop samples per replicate were acquired each week for the first 4 wks, and 10 samples per replicate were acquired each week thereafter. In 2005, 10 plant and drop samples per replicate were obtained each week for the first 5 wks, 8 samples per replicate were obtained on wk 6, and 5 samples per replicate were obtained on wk 7 through 9. In 2006, 12 plant and drop samples per replicate were obtained each week except for wks 4 and 9 when 24 samples per replicate were acquired. When lepidopteran larvae were found on cotton plants, they were collected and held in the laboratory for emergence of adult parasitoids. *Heliothis virescens* (F.) and *Helicoverpa zea* (Boddie) larvae were identified in the laboratory using Neunzig's (1969) description of immature stages of these 2 heliothines. Adult stink bugs were identified using the species key in McPherson and McPherson (2000). Stink bug adults with at least one tachinid egg on the exoskeleton were held in the laboratory for parasitoid emergence. Predators, parasitoids, and ascovirus infection were identified by the first author. Voucher specimens of all insects are held in the USDA-ARS, Crop Protection & Management Research Laboratory in Tifton, GA.

The biopesticide azadirachtin (Neem 7 Way [0.58 L/ha], Georgia Organic Solutions, LLC, Blakely, GA) was used for management of heliothine larvae in cotton. Azadirachtin was chosen over spinosad for management of heliothine larvae because spinosad can have a negative impact on some natural enemies (Tillman 2008). In 2006, except for the first sampling date, Karanja oil (0.58 L/ha, GA Organic Solutions, LLC, Blakely, GA) was mixed with azadirachtin because Karanja oil acts as a synergist enhancing the effect of insecticides (Sighamony et al. 1983). We used an economic threshold of 5% infestation of young heliothine larvae (1st and 2nd instars) on cotton plants because this is the generally accepted economic threshold for these pests in conventional cotton production (Jost 2004).

Statistical analysis. Insect density data were analyzed using the PROC MIXED procedure of the Statistical Analysis System (SAS Institute 2003). The fixed effects were treatment, week, and treatment × week. Random effects were replicate, replicate × treatment, replicate × location (treatment), replicate × sample (treatment × location), replicate × week, replicate × week (treatment), and residual error. Least squares means were separated by least significant difference (LSD, $P > 0.05$) (SAS Institute 2003) where appropriate.

Results and Discussion

Heliothine larvae. In 2004, factorial analysis revealed that there was a significant week effect for number of larvae of the heliothines *H. virescens* and *H. zea* per plant ($F = 8.34$, df = 9, 216, $P = 0.0001$) (Table 1). There was no significant treatment by week interaction ($F = 0.58$, df = 9, 216, $P = 0.8144$). Because a treatment effect was not detected ($F = 0.72$, df = 1, 48.6, $P = 0.3994$), irrigated and nonirrigated data were combined. Heliothine eggs and larvae were observed for the first time on cotton on 20 July. The peak number of heliothine larvae on cotton plants occurred the first week of August following 2 wks of heavy oviposition (80% of the plants infested with eggs) by female moths. In general in 2004, higher levels of heliothine larval infestations were observed in irrigated cotton than in nonirrigated cotton (Table 2). As mentioned earlier, the biopesticide azadirachtin (Neem 7 Way [0.58 L/ha]), was applied for management of these heliothine larvae in cotton although it could not be applied on 10 August due to rainy conditions and wet soil.

In 2005, factorial analysis revealed that there was no significant week effect ($F = 2.36$, df = 8, 12.8, $P = 0.0828$), treatment effect ($F = 0.09$, df = 1, 2.01, $P = 0.7917$), and treatment by week interaction ($F = 0.16$, df = 8, 12.8, $P = 0.9922$) for number of *H. virescens* and *H. zea* larvae per plant. When the treatment by week interaction was removed as a fixed effect, there was a significant week effect ($F = 3.56$, df = 8, 16.7, $P = 0.0137$) (Table 1). A significant treatment effect ($F = 0.07$, df = 1, 1.98, $P = 0.8227$) was not detected so irrigated and nonirrigated data were combined. Heliothine eggs and larvae were observed for the first time on transitional cotton on 4 August. Heliothine larvae were present on cotton throughout August and early September, and the number of heliothine larvae per plant peaked on 24 August.

With the exception of the last sampling date in 2005, percentage infestation by heliothine larvae was similar for irrigated and nonirrigated cotton (Table 2). Infestation of heliothine larvae generally remained between 10-15% in cotton throughout August. However, it was somewhat higher in irrigated cotton on 9 August and in both irrigation

Table 1. Least squares means for number of heliothine larvae per plant on transitional organic cotton, Shellman, GA, 2004-2006

No. heliothine larvae per plant						
2004		2005		2006		
Date	Both treatments	Date	Both treatments	Date	Irrigated	Non-irrigated
7/6	0c			7/7	0c1	0b1
7/13	0c	7/13	0c	7/13	0.04c2	0.15a1
7/20	0.17bc	7/22	0c	7/21	0.29a1	0b2
7/27	0.3b	7/28	0c	7/27	0.04c1	0.04ab1
8/5	1.15a	8/4	0.2b	8/3	0c1	0b1
8/10	0.48b	8/9	0.33b	8/10	0.17ab1	0b2
8/17	0.15c	8/16	0.31b	8/17	0.15b1	0b2
8/24	0.18bc	8/24	0.65a	8/24	0.13bc1	0.04ab1
8/31	0.13c	8/30	0.25b	9/1	0c1	0b1
9/8	0.03c	9/8	0.1bc	9/8	0c1	0b1

For 2004, least squares means within a column followed by the same lowercase letter are not significantly different between dates for heliothine larvae (PROC MIXED, LSD, $P > 0.05$, $n = 272$, SE = 0.22, df = 216). For 2005, least squares means within a column followed by the same lowercase letter are not significantly different between dates for heliothine larvae (PROC MIXED, LSD, $P > 0.05$, $n = 290$, SE = 0.11, df = 16.7). For 2006, least squares means within a column followed by the same lowercase letter are not significantly different between dates for heliothine larvae in irrigated and nonirrigated cotton, and least squares means within a row followed by the same number are not significantly different between treatments for heliothine larvae (PROC MIXED, LSD, $P > 0.05$, $n = 576$, SE = 0.04, df = 556).

treatments on 24 August. Azadirachtin was used for management of heliothine larvae on transitional cotton this year also, but the rate was increased from 0.58-1.75 L/ha. Unfortunately, due to rainy conditions and wet soil, the biopesticide could not be applied until 8 d after larvae were first observed in the plots. Inclement weather conditions also prevented application of the insecticide on 30 August and 8 September.

In 2006, factorial analysis revealed that there was a significant treatment by week interaction for the number of heliothine larvae per cotton plant ($F = 2.83$, df = 9, 556, $P = 0.0029$) (Table 1). Heliothine larvae were first observed on 13 July. On that sampling date, the number of heliothine larvae peaked on nonirrigated cotton, and heliothine immatures were significantly higher on nonirrigated cotton than on irrigated cotton. A week later on 21 July, the number of heliothine larvae peaked on irrigated cotton and was significantly higher in irrigated over nonirrigated cotton. This shift in apparent ovipositional preference of the heliothines probably was due to phenological differences in cotton plants over time, for nonirrigated plants developed more quickly than irrigated ones. By 3 August, heliothine larvae were no longer found on cotton, but they were present on this crop the last 3 wks of the month. On 10 and 17 August, the number of heliothine larvae per plant was significantly higher on irrigated cotton compared with nonirrigated cotton.

Table 2. Percent infestation of heliothine larvae, percent boll damage by stink bugs, and azadirachtin treatments for transitional organic cotton, Shellman, GA, 2004-2006

		% Heliothine infestation		% Stink bug boll damage	Azadirachtin treatment	
Year	Date	Irrigated	Non-irrigated	Both treatments	Date	Rate
2004	7/27	5	5	0		
	8/5	25	20	0	8/6	0.58 L/ha
	8/10	10	5	0		RA†
	8/17	35	10	0	8/20	0.58 L/ha
	8/24	35	5	0	8/25	0.58 L/ha
	8/31	30	5	0	9/1	0.58 L/ha
	9/8	1.0	0	0		
2005	8/4	7.5	12.5	5		RA
	8/9	20	12.5	15	8/12	1.75 L/ha
	8/16	12.5	10	35	8/22	1.75 L/ha
	8/24	30	35	50	8/26	1.75 L/ha
	8/30	15	10	85		RA
	9/8	10	0	75		RA
2006*	7/13	1.0	7.3	0	7/13	1.17 L/ha§
	7/21	14.6	0	0	7/21	1.17 L/haδ‡
	7/27	1.0	1.0	0		
	8/10	8.3	0	0	8/11	1.17 L/haδ
	8/17	7.3	0	0	8/21	1.17 L/haδ
	8/24	6.3	2.1	0	8/28	1.75 L/ha
	9/8	0	0	4.2		

* Except for first date in 2006, 0.58 L/ha of Karanja oil added to azadirachtin.
† Unable to treat with insecticide due to heavy rain.
§ Nonirrigated plots only.
δ Irrigated plots only.
‡ Rained hard soon after application of insecticide; repeated application on 24 July.

On 13 July 2006, percent heliothine infestation was higher than 5% for only nonirrigated cotton, thus on that sampling date azadirachtin (Neem 7 Way [1.17 L/ha]) was applied for control of these pests only on nonirrigated cotton (Table 2). On 21 July and 10 and 17 August, percent heliothine infestation was higher than the 5% level for only irrigated cotton. Therefore, the biopesticide was applied for control of these pests only on irrigated cotton on these dates. On 24 July, azadirachtin was reapplied for control of heliothine larvae because of a rainfall event immediately after the 21 July insecticide application.

Stink bugs. Generally, the most numerous stink bugs were *Nezara viridula* (L.), *Euschistus servus* (Say), and *Euschistus quadrator* (Rolston). Stink bugs were observed on cotton in relatively high numbers only during year 2 of the study (Table 3). *Nezara viridula* were higher in mid to late-August than for any other period of time (F = 3.01, df = 8, 11.5, P = 0.0444). Except for 1 week, *E. servus* were higher in August than in July and September (F = 2.42, df = 8, 272, P = 0.0153). There was no significant week effect (F = 1.05, df = 8, 8.97, P = 0.4697), treatment effect (F = 0.06, df = 1, 264, P = 0.8050), and treatment by week interaction (F = 1.32, df = 8, 264, P = 0.2344) for number of *E. quadrator* per drop sample, but generally, adults of *E. quadrator* were present mainly in August and the first portion of September. There was no significant week effect (F = 1.3, df = 8, 272, P = 0.2429), treatment effect (F = 0.27, df = 1, 272, P = 0.6045), and treatment by week interaction (F = 1.64, df = 8, 272, P = 0.1123) for number of red-shouldered stink bugs, *Thyanta custator accerra* McAtee, per drop sample; they were observed in low numbers. Rice stink bugs were present for only 1 day (28 July) at 0.05 per 1.82-m of row. There was no significant week effect (F = 1.02, df = 8, 5.84, P = 0.5050), treatment effect (F = 0.16, df = 1, 259, P = 0.6923), and treatment by week interaction (F = 0.73, df = 8, 259, P = 0.6685) for number of the spined soldier bug, *Podisus maculiventris* (Say), per drop sample. These predatory stink bugs were observed in low numbers.

In 2005, stink bug boll damage was first observed in early August and then continued to increase to high levels throughout August even after applying azadirachtin for control of these pests (Table 2). An economic threshold of 20% of the medium-sized

Table 3. Least squares means for number of phytophagous and predatory stink bugs per 1.82-m of row for transitional organic cotton, Shellman, GA, 2005*

Date	*N. viridula*	*E. servus*	*E. quadrator*	*T. c. accerra*	*P. maculiventris*
7/13	0b	0b	0.08a	0a	0a
7/22	0b	0b	0a	0a	0.03a
7/28	0b	0.08b	0a	0a	0a
8/4	0.08b	0.2a	0.08a	0.05a	0a
8/9	0.3b	0.08b	0.18a	0a	0a
8/16	0.36ab	0.27a	0.2a	0.1a	0a
8/24	0.8a	0.3a	0.25a	0a	0.05a
8/30	0.5a	0.2a	0.2a	0a	0a
9/8	0.2b	0.05b	0.15a	0a	0.1a

Least squares means within a column followed by the same lowercase letter are not significantly different between dates for *N. viridula* (PROC MIXED, LSD, P > 0.05, n = 290, SE = 0.15, df = 11.5), *E. servus* (PROC MIXED, LSD, P > 0.05, n = 290, SE = 0.07, df = 272), *E. quadrator* (PROC MIXED, LSD, P > 0.05, n = 290, SE = 0.09, df = 264), *T. c. accerra* (PROC MIXED, LSD, P > 0.05, n = 290, SE = 0.03, df = 272), and *P. maculiventris* (PROC MIXED, LSD, P > 0.05, n = 290, SE = 0.04, df = 259).

* Irrigated and nonirrigated plots combined.

cotton bolls (approx. 14 d old) with internal feeding damage is the generally accepted economic threshold for these pests in conventional cotton production (Jost 2004). It appeared that azadirachtin alone, at least at the rate used, was not very effective in preventing high levels of stink bug boll damage in these plots. Therefore, in 2006, kaolin clay (Surround [14 kg/ha], BASF Corp., Florham Park, NJ) was applied on 2 August to cotton with young fruit in an effort to prevent stink bugs from damaging cotton bolls. In this current study, the use of the compound may have worked because only 2 *E. quadrator* adults were found in cotton throughout the 2006 season, and boll damage was only observed on 8 September at a low level (4.2%). Other surrounding cotton fields had to be treated with an insecticide for control of stink bugs (Tillman, unpubl. data).

Predators. Over the 3-yr transitional period from conventional to organic production of cotton, the red imported fire ant, *Solenopsis invicta* Buren, the big-eyed bug, *Geocoris punctipes* (Say), the pirate bug, *Orius insidiosus* (Say), and various spiders, including *Oxyopes scalaris* Hentz, *Peucetia viridans* (Hentz), and many unknown species, were the most abundant heliothine and stink bug predators (Table 4). The red imported fire ant is known to prey on eggs and larvae of *H. zea* and *H. virescens* in cotton (Lofgren 1986). Using radioactive-tagged eggs, McDaniel and Sterling (1979, 1982) found that *S. invicta* was the most common predator of *H. virescens* eggs, and *S. invicta* workers were observed preying on 3rd and 4th instars of this pest on cotton in east Texas. This predator also has been reported to be an effective predator of *N. viridula* especially on eggs (Stam et al. 1987) and young nymphs (Krispyn and Todd 1982). We observed these predators feeding on eggs, nymphs, and adults of stink bugs in transitional organic cotton.

Geocoris punctipes and *O. insidiosus* are known to be effective predators of *H. zea* and *H. virescens* in cotton (Barber 1936, Bell and Whitcomb 1963, Lopez et al. 1976, McDaniel and Sterling 1979, 1982). Spiders, including *P. viridans*, *Oxyopes salticus* Hentz, *Phidippus audax* (Hentz), and *Neoscona arabesca* (Walckenaer), also are known to be predators of these heliothines (Whitcomb et al. 1963). *Podisus maculiventris* feeds on a variety of insect prey including the heliothines in a diverse array of habitats (McPherson et al. 1982). Using an enzyme linked immunosorbent assay (ELISA), Ragsdale et al. (1981) demonstrated that *G. punctipes* and *P. maculiventris* were effective predators of eggs and nymphs, *O. insidious* effectively preyed on eggs, and 3 species of spiders, *N. arabesca*, *O. salticus*, and *P. audax,* were predators of nymphs of *N. viridula*. In this study, *G. punctipes* and *O. insidiosus* were observed feeding on stink bug egg masses on transitional organic cotton. The predatory stink bug, *P. maculiventris*, was seen attacking and consuming nymphs of pest stink bugs. Adults and older nymphs of phytophagous stink bugs were observed to prey on nymphs of the same stink bug species, but only occasionally. Spiders were observed attacking and consuming nymphs of stink bugs. Generally, nymphs and adults of stink bug pests were very susceptible to predators during and soon after the molting process.

In 2004, no treatment ($F = 0.45$, df = 1, 1.94, $P = 0.5732$), week ($F = 2.58$, df = 9, 6.76, $P = 0.1164$), or treatment by week ($F = 0.76$, df = 9, 3.96, $P = 0.6647$) differences were detected for *S. invicta*. Nevertheless, a numerically higher number of *S. invicta* were observed in July compared with August (Table 4). The number of spiders per plant was significantly higher on 27 July than on any other sampling date ($F = 66.67$, df = 9, 230, $P = 0.0001$). A significantly higher number of *G. punctipes* per plant were found in early July compared with the rest of the season ($F = 8.42$, df = 9, 17, $P = 0.0001$). The number of *O. insidiosus* per plant was significantly higher on 8

Table 4. Least squares means for number of predators per plant on transitional organic cotton, Shellman, GA, 2004-2006*

2004					2005					2006				
Date	SI	SP	GP	OI	Date	SI	SP	GP	OI	Date	SI	SP	GP	OI
7/6	5.38a	0.2d	3.0a	0c						7/7	0.23b	0.2a	0d	0.04a
7/13	3.87a	1.75c	0.88b	0.37ab	7/13	0.68b	0.35b	0.33b	0.15a	7/13	0.68b	0.4a	0.1bcd	0.09a
7/20	4.25a	2.62b	1.38b	0c	7/22	5.93a	0.1b	0.05b	0a	7/21	0.4b	0.4a	0.31a	0.08a
7/27	8.5a	4.37a	1.13b	0c	7/28	4.08a	0.53b	0.05b	0.03a	7/27	2.27a	0.4a	0.25ab	0.06a
8/5	0.33a	0.25d	0c	0c	8/4	5.58a	0.23b	0.23b	0.03a	8/3	2.25a	0.6a	0.13bc	0.15a
8/10	0.13a	0.03d	0c	0.08bc	8/9	4.1a	0.75b	0.3b	0a	8/10	0.58b	0.2a	0.19ab	0.02a
8/17	0.05a	0d	0.05c	0.03c	8/16	1.19b	1.98a	0.21b	0.06a	8/17	2.69a	0.2a	0d	0a
8/24	2.55a	0d	0c	0.08bc	8/24	2.65b	1.85a	0.45ab	0.05a	8/24	0.33b	0.2a	0.04cd	0a
8/31	1.98a	0d	0.08c	0.03c	8/30	3.45ab	0.35b	0.9a	0.1a	9/1	0b	0a	0d	0a
9/8	1.81a	0d	0.03c	0.65a	9/8	1.5b	0.4b	0.9a	0.05a	9/8	0b	0a	0d	0a

For 2004, least squares means within a column followed by the same lowercase letter are not significantly different between dates for *S. invicta* (PROC MIXED, LSD, $P > 0.05$, $n = 272$, SE = 1.76, df = 6.76), spiders (PROC MIXED, LSD, $P > 0.05$, $n = 272$, SE = 0.18, df = 230), *G. punctipes* (PROC MIXED, LSD, $P > 0.05$, $n = 272$, SE = 0.34, df = 17), and *O. insidiosus* (PROC MIXED, LSD, $P > 0.05$, $n = 272$, SE = 0.12, df = 6.96). For 2005, least squares means within a column followed by the same lowercase letter are not significantly different between dates for *S. invicta* (PROC MIXED, LSD, $P > 0.05$, $n = 290$, SE = 0.94, df = 29.4), spiders (PROC MIXED, LSD, $P > 0.05$, $n = 290$, SE = 0.22, df = 7.42), *G. punctipes* (PROC MIXED, LSD, $P > 0.05$, $n = 290$, SE = 0.15, df = 6.47), and *O. insidiosus* (PROC MIXED, LSD, $P > 0.05$, $n = 290$, SE = 0.04, df = 263). For 2006, least squares means within a column followed by the same lowercase letter are not significantly different between dates for *S. invicta* (PROC MIXED, LSD, $P > 0.05$, $n = 576$, SE = 0.33, df = 28.8), spiders (PROC MIXED, LSD, $P > 0.05$, $n = 576$, SE = 0.03, df = 14.7), *G. punctipes* (PROC MIXED, LSD, $P > 0.05$, $n = 576$, SE = 0.06, df = 7.65), and *O. insidiosus* (PROC MIXED, LSD, $P > 0.05$, $n = 576$, SE = 0.05, df = 19.2).

* SI = *S. invicta*; SP = Spiders (*O. scalaris*, *P. viridans*, and unknown species); GP = *G. punctipes*; OI = *O. insidiosus*; irrigated and nonirrigated plots combined.

September compared with other sampling dates although this predator was found in relatively high numbers on 13 July. Overall in 2004, predator populations were higher in July than in August.

In 2005, factorial analysis revealed that there was a significant week effect for number of *S. invicta* per plant ($F = 4.22$, df = 8, 29.4, $P = 0.0018$) (Table 4). *Solenopsis invicta* were present for most of the season but occurred at higher levels early in the season compared with the rest of the season. The number of spiders per plant was higher on 16 and 24 August than on any other sampling date ($F = 9.09$, df = 8, 7.42, $P = 0.0035$). A significant week effect was detected for *G. punctipes* ($F = 4.33$, df = 8, 6.47, $P = 0.0397$). This predator was present in early July, but the population was significantly higher in late-August compared with the population for the rest of the season. No treatment ($F = 0.15$, df = 1, 1.97, $P = 0.7389$) or week ($F = 1.7$, df = 8, 263, $P = 0.0979$) differences were detected for *O. insidiosus*. Nevertheless, a relatively high number of *O. insidiosus* were observed the first sampling week.

In 2006, a significant week effect again was detected for *S. invicta* per cotton plant ($F = 12.26$, df = 9, 28.8, $P = 0.0001$) (Table 4). Except for one sampling date, the number of *S. invicta* was higher midseason compared with the rest of the season. No treatment ($F = 0.32$, df = 1, 7.87, $P = 0.588$), week ($F = 0.72$, df = 9, 14.7, $P = 0.6836$), or treatment by week ($F = 1.15$, df = 9, 14.7, $P = 0.3907$) differences were detected for spiders. Generally, spiders were equally present each week throughout the season. A significant week effect was detected for *G. punctipes* ($F = 4.91$, df = 9, 7.65, $P = 0.0196$). The peak number of *G. punctipes* was observed in cotton on 21 July when the peak number of heliothine larvae was present in irrigated cotton. No treatment ($F = 3.02$, df = 1, 20.2, $P = 0.0974$), week ($F = 1.63$, df = 9, 19.2, $P = 0.1757$), or treatment by week ($F = 1.0$, df = 9, 19.2, $P = 0.4720$) differences were detected for *O. insidiosus*. Nevertheless, this predator occurred mainly early to midseason. Generally, predators were relatively higher the last week of July and the first week of August.

Parasitoids. Over the 3-yr study, the endoparasitoid *Toxoneuron nigriceps* Viereck and an ascovirus also contributed to larval mortality of *H. virescens* (Table 5). The braconid, *T. nigriceps*, is a common parasitoid of *H. virescens* larvae and can mechanically transmit the ascovirus to larvae of this heliothine (Tillman et al. 2004, Tillman 2006a). Only 2 larvae of *H. zea* were parasitized by *Cotesia marginiventris* (Cresson) in 2005. In 2004, most (72.4%) of the heliothine larvae were *H. virescens*, and were present in both irrigated and nonirrigated cotton. Parasitization of these *H. virescens* larvae by *T. nigriceps* was moderate to high in cotton for both irrigation treatments. In 2005, only a few (10.9%) of the heliothine larvae collected were *H. virescens*, and larvae of this species were found equally in either irrigated or nonirrigated cotton only on 9 and 16 August. Only one of these *H. virescens* larvae was parasitized by *T. nigriceps*. In 2006, many (33.3%) of the heliothine larvae were *H. virescens*, but they were found only in irrigated cotton after 21 July. Parasitization of *H. virescens* larvae by *T. nigriceps* was high in irrigated cotton during late August. In 2004 and 2005, ascovirus infection of *H. virescens* larvae was relatively low and occurred only in irrigated cotton. It appears that even though *H. virescens* may sometimes have a preference for irrigated over nonirrigated cotton, the parasitoid readily parasitized these larvae in either irrigation treatment of cotton. In contrast, an ascovirus infection appears for some unknown reason to occur only in irrigated plots. Possibly a certain level of humidity is necessary for an ascovirus infection to develop in *H. virescens* larvae.

In 2005, the endoparasitoid *Trichopoda pennipes* (F.) parasitized *N. viridula* adults (Table 5). This tachinid of is one of the most effective natural enemies of this pest

Table 5. Percent parasitization by *T. nigriceps* and percent ascovirus infection for *H. virescens* larvae and percent parasitization of *N. viridula* by *T. pennipes* for transitional organic cotton, Shellman, GA, 2004-2006*

		T. nigriceps		Ascovirus	*T. pennipes*	
Year	Date	Irrigated	Non-irrigated	Irrigated	Irrigated	Non-irrigated
2004	7/27	0	100	0	-	-
	8/5	40.0	53.3	25.0	-	-
	8/10	30.8	80.0	15.4	-	-
	8/17	50.0	-	25.0	-	-
	8/24	-	-	-	-	-
	8/31	100	0	0	-	-
2005	8/24	-	-	-	85.7	44.4
	8/30	-	-	-	25.0	16.7
	9/8	-	-	-	50.0	50.0
2006	7/21	50.0	100.0	0	-	-
	8/10	14.3	-	0	-	-
	8/17	82.4	-	11.8	-	-
	8/24	66.7	-	33.3	-	-

* -, host insect not present.

(Jones 1988). Also, this parasitoid can survive residual, topical, and oral exposure to the organically-certified insecticide azadirachtin (Tillman 2008). Generally, percent parasitization of *N. viridula* by T. *pennipes* was similar for both irrigation treatments and ranged from low to high levels.

Overall, for the 3-yr transition from conventional to organic production of cotton, heliothines, including *H. virescens* and *H. zea*, and stink bugs, particularly *N. viridula*, *E. servus*, and *E. quadrator*, were the 2 major groups of insect pests found on cotton. Even though the plots were relatively small, the pest pressure and natural enemy populations observed in cotton during this transitional period were realistic when compared with those in conventional on-farm cotton (Tillman and Mullinix 2004, Tillman 2006b).

Heliothine larvae were a major pest management issue in transitional organic cotton mainly because the use of genetically engineered *Bt* cotton is prohibited in production of organic cotton (Sustainable Agriculture Network 2007). The biopesticide azadirachtin, though, appeared to effectively suppress heliothine larvae. Azadirachtin is found in seeds and leaves of the neem tree, *Azadirachta indica* A. Juss. It has been approved for use in organic crop production and has shown good biological activity against several species of noctuids including *H. virescens* and *Helicoverpa armigera* Hübner (Schmutterer 1990, Isman 1993, Yoshida and Toscano 1994, Neoliya et al. 2007). It acts as a repellent or antifeedant on phytophagous insects and also affects reproduction and development of pest insects by inhibiting oviposition and interfering with larval molts (Schmutterer 1990). This biopesticide has been suggested for use in IPM programs due to its selectivity against natural enemies (Schmutterer 1995).

Even though azadirachtin was applied to irrigated cotton in 2004, heliothine larvae remained at relatively high levels of infestation in this cotton throughout August. This was mainly due to 3 factors, a continuous and heavy oviposition by the heliothines for 4 wks, inclement weather which prevented application of the insecticide the second week of August, and a decline in predators the beginning of August. In addition, the rate of azadirachtin used may have been too low, and the first application of the insecticide may have been a little late. In 2005, control of the pest may have been more effective if the insecticide could have been applied in a timely manner. However, levels of infestation dropped in late August even though we were unable to apply the insecticide to cotton on 30 August and 8 September due to inclement weather. This reduction in level of heliothine infestation may have been due to increased predation of heliothine eggs and larvae, for *G. punctipes* populations increased during the latter part of the season in cotton. Similarly, in 2006 the reduction in the number of heliothine larvae per plant the last week of July and the first week of August may have been due in part to the relative increase in predators during that same time period. Percent infestation of heliothine larvae on cotton plants was generally lower for 2006 compared with the other 2 yrs of the study. This was probably due to several factors. Generally, the number of heliothine larvae per plant was lower in 2006 than in the other 2 yrs. In addition, inclement weather did not prevent timely application of the biopesticide azadirachtin, and Karanja oil was added to the biopesticide.

Stink bugs caused high levels of damage to cotton bolls only in 2005. Azadirachtin alone, at least at the rate used in this study, was not effective in preventing major stink bug boll damage in these plots. Surround appeared to act as a repellent against these pests in cotton in 2006. Surround is a kaolin-based particle film that has been approved for use in organic crop production. This processed kaolin is a nonabrasive, nontoxic sprayable particle barrier that has been reported to be effective against an array of pests (Glenn et al. 1999, Knight et al. 2000, Mazor and Erez 2004). The microsize particles form a protective barrier that control or suppress the pests by repelling or irritating the insects (Glenn et al. 1999). In conventional cropping systems, trap cropping has been shown to be an effective control strategy for *N. viridula* (McPherson and Newsom 1984, Rea et al. 2002), and sorghum can serve as a trap crop for both this stink bug pests and *H. zea* (Tillman and Mullinix 2004, Tillman 2006b). Capture traps baited with the *E. servus* pheromone (Cottrell 2001) have been certified for use in organic crop production. These pheromone-baited capture traps can be used in conjunction with a sorghum trap crop for managing *E. servus* (Tillman, unpubl. data). Thus, a combination of strategies may be needed for management of stink bugs in organically-produced cotton.

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