MANAGEMENT OF THE BEET ARMYWORM (LEPIDOPTERA: NOCTUIDAE) IN COTTON: ROLE OF NATURAL ENEMIES

John R. Ruberson[1,3], Gary A. Herzog[2], William R. Lambert[2], and W. Joe Lewis[1]
[1]Insect Biology and Population Management Research Laboratory United States Department of Agriculture, Agricultural Research Service Tifton, GA 31793

[2]Dept. of Entomology, University of Georgia, Tifton, GA 31793

[3]Current address: Dept. of Entomology, University of Georgia, P.O. Box 748, Tifton, GA 31793

Abstract

The beet armyworm, *Spodoptera exigua* (Hubner), has recently become a persistent and explosive pest of cotton in the southeastern United States. It is, however, attacked by a large and diverse complex of beneficial arthropods and pathogens that appear capable of maintaining beet armyworm populations below economically-damaging levels. Disruption of this complex contributes to outbreaks of *S. exigua*. It can

also exacerbate problems with other pests because the complex of beneficial organisms attacking the beet armyworm is comprised of generalist species that also suppress other pests in the cotton production system. Management of the beet armyworm through conservation of its natural enemies, therefore, provides multiple benefits to growers by managing other pests as well.

Key Words: Beet armyworm, cotton, biological control, *Spodoptera exigua*, parasitoid, predator

RESUMEN

El gusano trozador de la remolacha, *Spodoptera exigua*, recientemente se ha convertido en una plaga persistente y explosiva del algodón en el sureste de los Estados Unidos; sin embargo, es atacado por un complejo grande y diverso de artrópodos útiles y patógenos que parece ser capaz de mantener las poblaciones del gusano de la remolacha por debajo de los niveles de daño económico. La alteración de este complejo favorece la aparición de brotes del gusano trozador, pero también puede aumentar los problemas con otras plagas porque el complejo de los organismos útiles que atacan el gusano de la remolacha está compuesto de especies generalistas que también pueden suprimir otras plagas en el sistema de producción del algodón. Por lo tanto, el manejo del gusano de la remolacha mediante la conservación de sus enemigos naturales también ofrece beneficios múltiples a los granjeros en el manejo de otras plagas.

———————————

The beet armyworm, *Spodoptera exigua* (Hübner), is an introduced pest of numerous crops in the United States. It appears to be a native of southern Asia, although its origin is presently unclear. It was first reported in the United States with the collection of specimens in Oregon and California in 1876 (Harvey 1876). The insect dispersed across the country and was established in Florida by the late 1920s, where it was recorded feeding only on asparagus fern, gladiolus, and grasses (Wilson 1932). In the years since its introduction, the beet armyworm has become progressively more pestiferous in the United States on an increasingly wide range of crop plants (see Pearson 1982). Its current recorded host range in North America exceeds 90 plant species, including numerous important crop species such as corn, cotton, soybeans, peanuts, cabbage, tomatoes, and peppers (Pearson 1982). The bases for this apparent host range expansion are presently unclear; the changes suggest that this insect has considerable phenotypic plasticity in its host range [and likely genotypic, as is the case with the fall armyworm, *Spodoptera frugiperda* (Pashley, pers. comm.)] and thus it may become an increasingly widespread pest in the future.

In addition to its broad host range, there are several facets of *S. exigua*'s biology that may predispose it to being an explosive pest. First, *S. exigua* has a relatively brief developmental time under field conditions (Ali & Gaylor 1991), permitting rapid cycling of generations. Second, it has a high reproductive capacity, with average calculated fecundities ranging from 604.7 to 1724.7 eggs per female (Wilson 1934, Hogg & Gutierrez 1980, Chu & Wu 1992). A simple calculation illustrates this point. Assuming a population sex ratio of 1 female to 1 male, a realized field fecundity of 200 eggs (approx. 2 egg masses) per female, and restricted emigration and immigration, 99% mortality within a generation would be necessary to simply maintain the population at a constant size. Thus, suppression of this pest requires high levels of mortality to counterbalance its high fecundity. Third, these insects are highly mobile and are thus capable of colonizing wide-ranging areas (French 1969, Mitchell 1979). Finally, insec-

ticides typically provide less than adequate control (e.g., Cobb & Bass 1975, Meinke & Ware 1978, Brewer & Trumble 1989, Wolfenbarger & Brewer 1993). This is due, at least in part, to the insect's innate tolerance of many insecticidal materials at recommended field rates. But the beet armyworm's ovipositional and feeding biology also influences insecticide efficacy. Females oviposit eggs in masses of 46 to 230 eggs ($x \pm$ SD = 99.4 ± 40.6; n = 75 field-collected egg masses; J.R.R. unpubl.), typically on the undersurface of leaves in the lower plant canopy. Insecticide coverage is often inadequate in these areas, particularly after the canopy has expanded. Further, beet armyworm larvae feed in groups through the first and second instars, then disperse as third instars (Poe et al. 1973). This feeding behavior concentrates a large proportion of the population into a relatively small area during the period when the larvae are most susceptible to insecticides. Thus, to kill a sufficient number of larvae to attain control, the material must contact a relatively small proportion of the plant canopy in the plant region most difficult to cover — a very difficult proposition when the plants are large and the canopy is closed.

Despite its pestiferous potential, the beet armyworm has been historically a sporadic and minor pest of cotton in the southeastern United States (Smith 1989). In recent years, however, it has become a persistent and serious cotton pest in the southeastern and mid-southern United States, especially in regions conducting the Boll Weevil Eradication Program (e.g., Fig. 1). However, the current ubiquity and consistency of the outbreaks, both inside and outside of active eradication zones, suggest that this pest has become a more widespread and serious cotton pest for reasons independent of the Boll Weevil Eradication Program. However, this program likely provides a ready opportunity for the beet armyworm to escape natural controls.
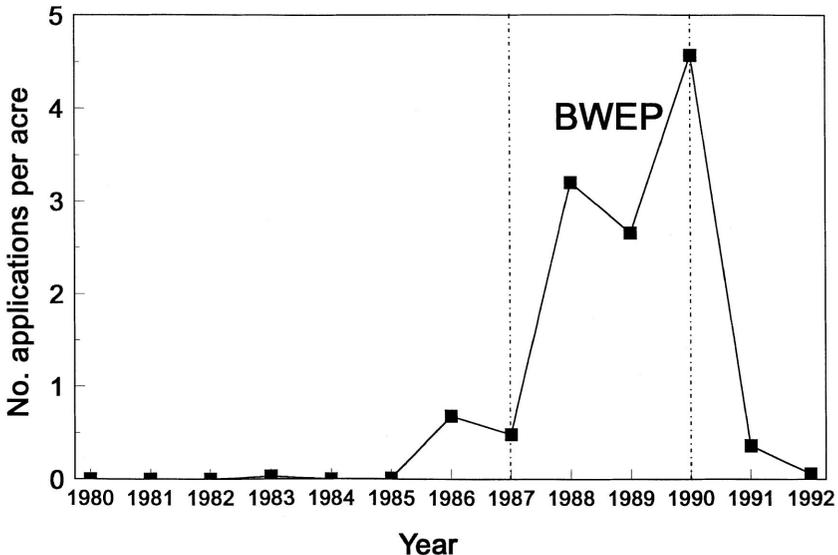

Fig. 1. Number of specific beet armyworm insecticide treatments applied per acre of cotton production in the state of Georgia from 1980 to 1992. "BWEP", demarcated by the vertical dashed lines, indicates the period when the Boll Weevil Eradication Program was in its active phase in the state.

Regardless of the cause, it is critical at this juncture to devise efficacious, biorational pest management approaches.

Natural enemies appear to be a key element in the management of the beet armyworm. In 1973, Eveleens et al. demonstrated that beet armyworm outbreaks could be induced by applications of organophosphate insecticides in cotton. Cotton can support a large and diverse complex of beneficial arthropods (Whitcomb & Bell 1964, van den Bosch & Hagen 1966) and in production systems receiving multiple treatments of highly toxic materials, such as organophosphates and pyrethroids, these complexes can be seriously disrupted for the remainder of the growing season. Subsequently, in the absence of the beneficial arthropods, production of an acceptable crop will require continued, repeated use of insecticides. The Boll Weevil Eradication Program relies on widespread, repetitive applications of organophosphates to suppress and eventually eliminate boll weevil populations (USDA-APHIS 1991).These treatments have a profound detrimental impact that releases beet armyworm populations from their natural biological control agents (e.g., Wilkinson et al. 1979).

Natural Enemies of the Beet Armyworm

The large number of predators and parasitoids that have been found associated with beet armyworm eggs and larvae are listed in Tables 1 and 2. This complex of natural enemies differs among various geographic regions; however, there are common linkages. Several parasitoid species, for example, have been found across the cotton belt, including the braconids *Cotesia marginiventris*, *Meteorus autographae*, *Chelonus insularis*, the ichneumonid *Temelucha* sp., and the tachinid *Lespesia archippivora* (Table 2). Their relative abundance and efficacy, however, vary among regions. Similarly, several genera of predators are shared across the cotton belt. It is noteworthy that the most commonly encountered natural enemies of the beet armyworm in all regions are generalists that attack a variety of hosts in multiple habitats. Given that the beet armyworm is an introduced pest, such a pattern is to be expected in the absence of specific imported biological control agents.

In addition to predators and parasitoids, several pathogens have also been recovered from the beet armyworm. A nuclear polyhedrosis virus has been widely reported (Oatman & Platner 1972, Eveleens et al.1973, Pearson 1982, Kolodny-Hirsch et al. 1993). Fungal pathogens, however, can also be important. Wilson (1933) reported that a fungus, described at the time as *Spicaria prasina* (probably *Nomuraea rileyi*), decimated populations of beet armyworm larvae during wet weather. In our studies in Georgia, we have observed larvae infected with the fungi *Erynia* sp. nr. *pieris* (identified by Dr. Donald Steinkraus, Univ. of Arkansas) and *N. rileyi*. Of these two species, *Erynia* was the most commonly encountered.

Despite the large number of natural enemies cataloged to date, there are few data to demonstrate their impact on beet armyworm populations. Eveleens et al. (1973) demonstrated in California that beet armyworm outbreaks could be induced by applications of organophosphate insecticides, which presumably disrupt the natural enemy complex. They suggested that predators were the most important mortality agents for the beet armyworm populations in their study, and that the greatest loss occurred in the egg and early larval stages. Hogg & Gutierrez (1980) also observed high rates of loss for eggs and small larvae of the beet armyworm in cotton in California and also attributed much of this loss to predators.

De Clercq & Degheele (1994) recently demonstrated in the laboratory that the native predaceous pentatomid *Podisus maculiventris* can consume large numbers of all stages of beet armyworm. It is, however, particularly destructive to eggs (ranging from 53.5 eggs consumed during the second instar to 111.6 eggs consumed per day by

TABLE 1. PREDATORS OBSERVED IN ASSOCIATION WITH BEET ARMYWORM EGGS OR YOUNG LARVAE IN THE UNITED STATES.

Taxon/Species	State Association[1]	Location	References
Dermaptera			
Labidura riparia	E, L	Georgia	Ruberson et al. 1994
Heteroptera			
Orius insidiosus	E, L	Georgia	Ruberson et al. 1994
Orius tristicolor	E, L	California	Eveleens et al. 1973; Hogg and Gutierrez 1980
Geocoris pallens	E, L	California	Eveleens et al. 1973; Hogg and Gutierrez 1980
Geocoris punctipes	E, L	Georgia	Ruberson et al. 1994
Geocoris uliginosus	E, L	Georgia	Ruberson et al. 1994
Podisus maculiventris	L	Florida	Wilson 1933;
		Georgia	Ruberson et al. 1994
Nabis roseipennis	L	Georgia	Ruberson et al. 1994
Nabis americoferus	E, L	California	Eveleens et al. 1973
Zelus sp.	E, L	Georgia	Ruberson et al. 1994
		California	Eveleens et al. 1973
Sinea sp.	E, L	California	Eveleens et al. 1973
Neuroptera			
Chrysoperla carnea	E, L	California	Eveleens et al. 1973; Hogg and Gutierrez 1980
Chrusoperla refilabris	E, L	Georgia	Ruberson et al. 1994
Hemerobius sp.	E, L	Georgia	Ruberson et al. 1994
Coleoptera			
Collops	E, L	California	Eveleens et al. 1973
Notoxus calcaratus	E, L	California	Eveleens et al. 1973
Coccinella septempunctata	E	Georgia	Ruberson et al. 1994
Hymenoptera			
Polistes fuscatus	L	Florida	Wilson 1933
Solenopsis invicta	E, L	Georgia	Ruberson et al. 1994
Arachnida			
Unidentified (3 species)	L	Georgia	Ruberson et al. 1994
Unidentified		California	Eveleens et al. 1973

[1]Stage association indicates with which stages of beet armyworm the predators were found; E = eggs and L = larvae.

adult female predators) and small larvae. Also, most life stages of beet armyworm are reportedly suitable prey for predator development. These data provide a glimpse into the possible impact of predators on beet armyworms, although *P. maculiventris* appears to be only a small, and inconsistent, part of the total natural enemy complex in the field. The overall impact of natural enemies in the field, however, is poorly delin-

TABLE 2. PARASITOIDS OF BEET ARMYWORM EGG AND LARVAE RECORDED IN THE UNITED STATES.

Taxon/Species	Stages Attacked[1]	Location	References
Diptera: Tachinidae			
Lespesia archippivora	L1-L5	California	van den Bosch & Hagen 1966; Henneberry et al. 1991; Eveleen et al. 1973
		Texas	Harding 1976
		Oklahoma	Soteres et al. 1984
		Georgia	Ruberson et al. 1993
Eucelatoria armigera		California	van den Bosch & Hagen 1966; Henneberry et al. 1991
Eucelatoria rubentis		Florida	Wilson 1933; Tingle et al. 1978
Eucelatoria sp. nr. *armigera*		California	Henneberry et al. 1991
Winthemia rufopicta		Florida	Tingle et al. 1978
Archytas californiae		California	Eveleens et al. 1973
Archytas apicifer		California	Henneberry et al. 1991
Archytas marmoratus		Georgia	Ruberson et al. 1994
Voria ruralis		California	Eveleens et al. 1973
Chaetogodia monticola		Hawaii	Swezey 1935
Gonia crassicornis		Florida	Wilson 1933
Hymenoptera: Braconidae			
Cotesia marginiventris	L1-L4	California	van den Bosch & Hagen 1966; Pearson 1982; Henneberry et al. 1991
		Oklahoma	Soteres et al. 1984
		Florida	Wilson 1933; Tingle et al. 1978
		Georgia	Ruberson et al. 1993
Cotesia laeviceps		U.S.	Krombein et al. 1979
Cotesia militaris		No. America	Krombein et al. 1979
Meteorus autographae	L1-L4	Florida	Wilson 1933; Tingle et al. 1978
		Georgia	Ruberson et al. 1993
		Texas	Harding 1976
Meteorus leviventris		Texas	van den Bosch & Hagen 1966; Harding 1976
Meteorus rubens		California	Henneberry et al. 1991
Meteorus laphygmae			Krombein et al. 1979

[1]"Stages attacked" signifies larval instars (L1-L5) and eggs (E) susceptible to parasitization by the respective parasitoids.
[2]Oviposits in eggs and emerges from the late larval stages.

TABLE 2.(CONTINUED) PARASITOIDS OF BEET ARMYWORM EGG AND LARVAE RECORDED IN THE UNITED STATES.

Taxon/Species	Stages Attacked[1]	Location	References
Chelonus insularis	E-L5[2]	California	van den Bosch & Hagen 1966; Eveleens et al. 1973; Pearson 1982; Henneberry et al. 1991
		Texas	Harding 1976
		Oklahoma	Soteres et al. 1984
		Florida	Wilson 1933; Tingle et al. 1978
		Georgia	Ruberson et al. 1993
Aleiodes laphygmae	L1-L3	Georgia	Ruberson et al. 1993
Cremnops haemotodes		California	Henneberry et al. 1991
Zele melea		Oklahoma	Soteres et al. 1984
Hymenoptera: Ichneumonidae			
Hyposoter exiguae	L1-L3	California	van den Bosch & Hagen 1966; Eveleens et al. 1973; Pearson 1982; Henneberry et al. 1991
Hyposoter annulipes		U.S.	Krombein et al. 1979
Pristomerus spinator	L1-L3	California	Eveleens et al. 1973; Pearson 1982; Henneberry et al. 1991
		Oklahoma	Soteres et al. 1984
Campoletis argentifrons		U.S.	van den Bosch & Hagen 1966
Campoletis flavicincta	L1-L3	Georgia	Ruberson et al. 1993
Campoletis sonorensis	L1-L3	U.S.	Krombein et al. 1979
		Oklahoma	Soteres et al. 1984
Temelucha sp.		California	Pearson 1982; Henneberry et al. 1991
		Florida	Tingle et al. 1978
Nepiera fuscifemora		West U.S.	Krombein et al. 1979
Ophion sp.		Georgia	Ruberson et al. 1993
Therion longipes		California	van den Bosch & Hagen 1966; Eveleens et al. 1973
Rubicundiella perpturbatrix		West U.S.	van den Bosch & Hagen 1966; Krombein et al. 1979
Sinophorus caradrinae (?)		Colorado	Krombein et al. 1979

[1]"Stages attacked" signifies larval instars (L1-L5) and eggs (E) susceptible to parasitization by the respective parasitoids.
[2]Oviposits in eggs and emerges from the late larval stages.

Table 2.(Continued) Parasitoids of beet armyworm egg and larvae recorded in the United States.

Taxon/Species	Stages Attacked[1]	Location	References
Hymenoptera: Eulophidae			
Euplectrus plathypenae	L3-L5	Florida	Wilson 1933
Hymenoptera: Trichogrammatidae			
Trichogramma spp.	E	California	van den Bosch & Hagen 1966

[1]"Stages attacked" signifies larval instars (L1-L5) and eggs (E) susceptible to parasitization by the respective parasitoids.
[2]Oviposits in eggs and emerges from the late larval stages.

eated and/or entirely unknown in the southeastern U.S. where beet armyworm problems have recently been most severe.

Impact of Natural Enemies on Beet Armyworm Populations in Georgia

We have undertaken various field studies in Georgia in an effort to characterize mortality factors and levels for beet armyworm populations.These studies have focused on two areas: 1) characterization and quantification of beet armyworm parasitoids and pathogens, and 2) determination of their impact on survival of eggs, small larvae, and pupae.

Larval Mortality: Impact of Parasitoids and Pathogens

Beet armyworm larvae of all ages were sampled from commercial cotton fields in Georgia in 1992 and 1993 (see Ruberson et al. 1993 for details). Collections were made on various dates from 15 July to 16 September in 1992 and from 24 May to 12 October in 1993. Totals of 7,545 and 7,072 larvae were collected in 1992 and 1993, respectively. The parasitoids reared from these larvae (in relation to instar collected) are presented in Table 3, with rates of parasitism by each species. The parasitism rates for the two years, pooled across larval instars and collection locales, were 46.8% and 40.2% in 1992 and 1993, respectively. The majority of parasitism, and resultant larval mortality, occurred in the early instars. In both years, *C. marginiventris* was the predominant species, and it accounted for more of the parasitism in 1993 than it did in 1992, particularly in the second and third instars (Table 3). This contrasts with results from California indicating that the tachinid *L. archippivora* and the braconid *C. insularis* were the most important parasitoids in cotton and alfalfa, respectively (Henneberry et al. 1991, and Pearson 1982, respectively). Soteres et al. (1984) also found *C. insularis* to be the most common parasitoid attacking beet armyworms in alfalfa in Oklahoma. *C. marginiventris*, however, is the dominant parasitoid of beet armyworm larvae from pigweed in Florida (Tingle at al. 1978). Thus, *C. marginiventris* appears to be the more dominant species in the eastern half of the United States, whereas *C. insularis* is more dominant in the west.

Cotesia marginiventris is highly attracted to plants damaged by beet armyworm feeding (e.g., Turlings et al. 1991), and this response is intensified by the clumped

TABLE 3. PARASITISM RATES (%) IN POPULATIONS OF BEET ARMYWORM LARVAE COL-
LECTED IN GEORGIA COTTON IN 1992 AND 1993. LARVAE WERE COLLECTED
FROM BARTOW, BEN HILL, DECATUR, DOOLY, LAURENS, MILLER, SEMI-
NOLE, AND TIFT COUNTIES.

	% Parasitism of Beet Armyworm Larval Instar[1]				
Parasitoid	1	2	3	4	5
1992					
Cotesia marginiventris	37.0	37.5	37.0	3.4	1.5
Aleiodes laphygmae	0.06	0.6	0.3	0.0	0.0
Meteorus autographae	4.7	10.6	7.6	3.4	0.0
Chelonus insularis	0.6	0.9	0.9	2.0	0.0
Lespesia archippivora	0.07	0.8	2.2	4.1	3.3
Ichneumonidae[2]	1.0	0.4	1.3	0.3	8.2
Unknown parasites	0.2	0.5	1.3	1.0	0.0
Total % parasitism	43.6	51.2	50.6	14.2	13.0
No. larvae collected	2977.0	2701.0	1512.0	294.0	61.0
1993					
Cotesia marginiventris	35.8	58.5	63.4	2.9	0.2
Aleiodes laphygmae	0.0	0.8	0.0	0.0	0.0
Meteorus autographae	0.0	0.1	0.7	0.1	0.0
Cardiochiles nigriceps	0.0	0.0	0.1	0.0	0.0
Pristomerus spinator	0.0	0.3	0.9	0.8	0.0
Lespesia archippivora	0.02	0.3	0.8	0.6	2.2
Archytas marmoratus	0.0	0.0	0.03	0.5	0.5
Unknown parasites	0.02	0.1	1.1	0.4	0.8
Total % parasitism	35.8	60.1	67.0	5.3	3.7
No. larvae collected	2914.0	1542.0	1207.0	768.0	641.0

[1]Instar of larvae at time of collection.
[2]Includes *Campoletis sonorensis*, *Pristomerus spinator*, and *Ophion* sp.

feeding behavior of the beet armyworm larvae on cotton plants [A. Datema (Wagenin-
gen, The Netherlands), J.R.R., and W.J.L., unpubl.]. This parasitoid, therefore, is
highly-attuned to locating clusters of beet armyworm larvae. It is, however, suscepti-
ble to several organophosphate and pyrethroid insecticides (Wilkinson et al. 1979, Ru-
berson et al. 1993), which could limit its efficacy in conventional, chemical-intensive
cotton production.

Several pathogens were also recovered from larvae collected in the field, although
disease did not appear to be a substantial mortality factor. The most commonly-en-
countered pathogen was the fungus *Erynia* sp. nr. *pieris* (determined by Dr. Donald
Steinkraus, Univ. of Arkansas), which killed 6.2% of the larvae collected in 1992, but
only 0.3% of those collected in 1993 (there was exceptionally little rain that year). A
few specimens collected in 1992 were infected with *N. rileyi*, but no *N. rileyi* was ob-
served in 1993. A nuclear polyhedrosis virus was found in 1.8% of the larvae collected

in 1992 and in 0.1% of the larvae in 1993. In addition, a single larva infected with an ascovirus (determined by Dr. John J. Hamm, USDA-ARS, Tifton GA) was collected in 1992. The senior author and J.J. Hamm (USDA-ARS, Tifton, GA) found this virus to be a poor pathogen of beet armyworm larvae in laboratory tests.

Overall parasitoid- and pathogen-related mortality from our collections ranged from approximately 40 to 50%. These overall rates were generally higher than those observed in the California studies noted above (Pearson 1982, Henneberry et al. 1991). However, Pearson (1982) did observe comparable parasitism levels for larvae on alfalfa in the late summer and early fall in Imperial Valley. This level of mortality comprises a relatively high level of loss in the population, but is well below the 99% needed to maintain or suppress the pest population.

Impact of Predation on Eggs, Larvae, and Pupae.

Two studies were undertaken to examine loss of beet armyworms in the field. The first examined the rate of loss for eggs and small larvae to assess loss prior to, and in the initial periods of susceptibility to parasitization. The second study addressed the loss of beet armyworm pupae in the soil.

Egg/Larvae Predation. The study to determine egg/larval losses was conducted from 16 to 27 August, 1993, in cotton plots in Tift County, Georgia. Beet armyworm egg masses (approximately 100 eggs each), laid on wax paper, were attached to the undersides of leaves in each of four 0.5 acre plots. Two of the plots received weekly applications of conventional insecticide (the pyrethroid l-cyhalothrin) beginning the first week in July, whereas the other plots were untreated. Insecticide was applied in the treated plots immediately prior to, and twice during, the experiment. Twenty-four egg masses were placed in each plot (approximately 1 per 1000 plants; action threshold is 2-3 per 100 plants). Egg masses were observed daily for hatching and for indications of predation. After hatching, the wax paper was removed, surviving larvae were observed and counted 2, 4, 6, and 8 days post-hatch, and the presence and identity of predators on the leaves near the larval groups were recorded.

High rates of loss were noted for egg masses exposed to predators in both the treated and untreated cotton, although loss was faster in the absence of insecticides (Table 5). Twice as many egg masses were entirely destroyed in the untreated cotton, however, as in the treated cotton. Most of the loss occurred in the egg and early-larval stages, as was suggested by Eveleens et al. (1973) and Hogg & Gutierrez (1980). We attribute this loss to predator activity. Thus, survival of beet armyworms was enhanced in the insecticide-treated plots.

More predators were observed in association with the beet armyworm eggs and larvae in the untreated cotton than in the treated cotton (Table 4). For example, only larvae of the green lacewing, *Chrysoperla rufilabris* were found associated with beet armyworm eggs in the treated plots, compared with 11 different predators in the untreated plots. Thus, insecticide treatments disrupted a major portion of the beneficial arthropod complex.

Two constraints limit the general applicability of these data concerning predation of beet armyworms. First, the plots were small, and widespread recolonization of treated plots by predators from adjacent untreated areas would be more rapid in these plots than would be the case for large cotton fields. Second, the density of beet armyworm egg masses placed in the plots was very low, which provided an excellent opportunity for the resident beneficial populations to eliminate them.However, this second point has some positive ramifications. Our data suggest that a conserved predator complex is capable of greatly reducing, and perhaps eliminating, low populations of the beet armyworm. Thus, the predator complex may be invaluable for eliminating

TABLE 4. PREDATORS, AND THEIR FREQUENCY, FOUND IN ASSOCIATION WITH BEET ARMYWORM EGGS AND LARVAE IN TREATED (PYRETHROID INSECTICIDE) AND UNTREATED COTTON (16-27 AUGUST 1993; TIFT. CO., GEORGIA).[1]

Predator Taxon/Species	Untreated Cotton		Treated Cotton	
Heteroptera				
Orius insidiosus	E (5, 8)	L (2, 3)	E (0, 0)	L (3, 3)
Geocoris punctipes	E (2, 3)	L (3, 3)	E (0, 0)	L (0, 0)
Geocoris uliginosus	E (1, 1)	L (1, 1)	E (0, 0)	L (0, 0)
Nabis roseipennis	E (1, 1)	L (2, 3)	E (0, 0)	L (0, 0)
Zelus sp.	E (1, 2)	L (1, 1)	E (0, 0)	L (0, 0)
Posisus maculiventris	E (1, 1)	L (1, 1)	E (0, 0)	L (0, 0)
Dermaptera				
Labidura riparia	E (1, 1)	L (2, 4)	E (0, 0)	L (0, 0)
Coleoptera				
Coccinella 7-punctata	E (0, 0)	L (1, 1)	E (0, 0)	L (1, 1)
Neuroptera				
Chrysoperla rufilabris	E (2, 2)	L (5, 7)	E (2, 2)	L (0, 0)
Hemerobius sp.	E (1, 1)	L (0, 0)	E (0, 0)	L (1, 2)
Diptera				
Syrphid	E (0, 0)	L (1, 1)	E (0, 0)	L (0, 0)
Hymenoptera				
Solenopsis invicta	E (3, 24)	L (3, 16)	E (0, 0)	L (3, 21)
Araneida				
Spiders	E (1, 1)	L (1, 1)	E (0, 0)	L (0, 0)
Totals	E (19, 45)	L (23, 42)	E (2, 2)	L (8, 27)

[1]E = egg masses, L = larval clutches. The numbers in parenthesis after each letter are, respectively, 1) the number of egg masses or larval clutches on which the predator was found, and 2) the total number of the predator taxon observed in association with beet armyworm eggs or larvae.

incipient beet armyworm populations, at least until sufficient egg and larval populations are present in the field to outstrip the predators' capacity to consume a substantial majority of the eggs and larvae.

Pupal Mortality. We examined loss in the pupal stage by placing ultimate-instar beet armyworm larvae under a styrofoam cup, with an opened, 30-ml diet cup containing artificial diet and a larva on the soil surface. Larvae were placed in two plots (100 per plot) of each of two treatments, insecticide-treated and unsprayed. A styrofoam collar (9 cm diam) into which the covering cup fit snugly was forced into the ground until its rim was level with the soil surface (about 6 cm). This prevented escape of the larvae because beet armyworms pupate in the upper 2-3 cm of soil. The opened diet cup with larva was then placed inside the collar and a styrofoam cup, which fit snugly into the collar, was placed over the cup with the insect. After the larvae had entered the soil and pupated, the covering cups were removed to expose the pupation sites to biotic and abiotic conditions in the field. Twenty additional cups and larvae were set up, with the covering cups left in place to trap the adult moths at emergence. These sentinel larvae were observed every day for adult emergence. When

TABLE 5. LOSS OF BEET ARMYWORM EGG MASSES, EGGS AND LARVAE IN TREATED AND UNTREATED COTTON (MEAN ± SD; 16-27 AUGUST, 1993.)

Days of Exposure	No. Egg Masses Remaining		No. Larvae Remaining/Egg Mass	
	Treated	Untreated	Treated	Untreated
0	24 ± 0.0	24 ± 0.0	97.0 ± 9.07	100.5 ± 9.01
H[1]+2	23.0 ± 1.4	15.0 ± 4.2	18.6 ± 18.1	18.2 ± 13.4
H+4	17.0 ± 0.0	10.0 ± 2.8	15.1 ± 14.6	13.7 ± 11.7
H+6	9.0 ± 1.4	4.5 ± 0.7	11.3 ± 15.5	6.0 ± 3.8
H+8	4.0 ± 1.4	0.5 ± 0.7	3.5 ± 2.8	1.0 ± 0.0

[1]"H" refers to hatch. Thus "H+2" means 2 days after egg hatch.

adult emergence was complete in the sentinel cups, all pupation sites were excavated, and the status of the pupal remains determined.

Loss of pupae was surprisingly high in both treatments. Only 42.3% ± 2.12 (SD) of the pupae produced adult moths in the treated plots, compared with 21.0% ± 0.28 pupae surviving to adult emergence in the untreated plots. Thus, loss in the untreated plots was twice that observed in the insecticide-treated plots, although both treatments sustained fairly high mortality.

Much of the loss observed in the experiment may be attributable to activity of imported fire ants, *Solenopsis invicta*. Fire ants were abundant in both fields, although they appeared to be more common in the untreated cotton than in the treated plots. Fire ants were observed removing pupal parts from pupation sites during the experiment; such sites afterward yielded no signs of pupal remains when excavated.

CONCLUSIONS

Although some of the results reported above are preliminary, summing up all of the mortality factors and their impacts yields a mortality rate in excess of 99% in untreated cotton. This suggests that the natural enemy complex functioning in cotton has the capacity to suppress beet armyworm populations. This conclusion, suggested by the California research reviewed above, points to the necessity of conserving the natural enemies for effective suppression of the beet armyworm. The completion of the active phase of the Boll Weevil Eradication Program in most of Georgia has provided the cotton production system an enormous opportunity to utilize natural enemies. In the absence of early-season applications of organophosphate insecticides to control the boll weevil, the natural enemy populations are able to increase in the cotton crop, and use of selective insecticides on a strictly as-needed basis will permit growers to realize the full benefits of these natural enemies. Under this system, the beet armyworm should not be a serious pest, except in cases where other pest control approaches disrupt the complex of resident beneficial organisms. Growers will reap benefits, however, beyond the natural control of beet armyworm populations. The complex of natural enemies that attacks the beet armyworm is comprised of generalists that will also provide some level of suppression of other arthropod pests in the system, as well, and benefit the overall cotton insect management program.

REFERENCES CITED

ALI, A. M., AND M. J. GAYLOR. 1991. Effects of temperature and larval diet on development of the beet armyworm (Lepidoptera: Noctuidae). Environ. Entomol. 21: 780-786.

BREWER, M. J., AND J. T. TRUMBLE. 1989. Field monitoring for insecticide resistance in beet armyworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 86: 1520-1526.

CHU, Y., AND H. WU. 1992. The studies on emergence, copulation and oviposition of adult beet armyworm (*Spodoptera exigua* Hübner). Chinese J. Entomol. 12: 91-99 (in Chinese).

COBB, P. P., AND M. H. BASS. 1975. Beet armyworm: dosage-mortality studies on California and Florida strains. J. Econ. Entomol. 68: 813-814.

DE CLERCQ, P., AND D. DEGHEELE. 1994. Laboratory measurement of predation by *Podisus maculiventris* and *P. sagitta* (Hemiptera: Pentatomidae) on beet armyworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 87: 76-83.

EVELEENS, K. G., R. VAN DEN BOSCH, AND L. E. EHLER. 1973. Secondary outbreaks of beet armyworm by experimental insecticide applications in cotton in California. Environ. Entomol. 2: 497-503.

FRENCH, R. A. 1969. Migration of *Laphygma exigua* Hübner (Lepidoptera: Noctuidae) to the British Isles in relation to large-scale weather systems. J. Anim. Ecol. 38: 199-210.

HARDING, J. A. 1976. *Heliothis* spp.: parasitism and parasites plus host plants and parasites of the beet armyworm, diamondback moth and two tortricids in the Lower Rio Grande Valley of Texas. Environ. Entomol. 5: 669-671.

HARVEY, L. F. 1876. New California and Texas moths. Canadian Entomol. 8: 54.

HENNEBERRY, T. J., P. V. VAIL, A. C. PEARSON, AND V. SEVACHERIAN. 1991. Biological control agents of noctuid larvae (Lepidoptera: Noctuidae) in the Imperial Valley of California. Southwest. Entomol. 16: 81-89.

HOGG, D. B., AND A. P. GUTIERREZ. 1980. A model of the flight phenology of the beet armyworm (Lepidoptera: Noctuidae) in Central California. Hilgardia 48: 1-36.

KOLODNY-HIRSCH, D. M., D. L. WARKENTIN, B. ALVAREZ-RODRIGUEZ, AND R. KIRKLAND. 1993. *Spodoptera exigua* nuclear polyhedrosis virus as a candidate viral insecticide for the beet armyworm (Lepidoptera: Noctuidae). J. Econ. Entomol. 86: 314-321.

KROMBEIN, K. V., P. D. HURD, D. R. SMITH, AND B. D. BURKS. 1979. Catalog of the Hymenoptera in America north of Mexico. Smithsonian Instit. Press, Washington DC.

MEINKE, L. J., AND G. W. WARE. 1978. Tolerance of three beet armyworm strains in Arizona to methomyl. J. Econ. Entomol. 71: 645-646.

MITCHELL, E. R. 1979. Migration by *Spodoptera exigua* and *S. frugiperda* — North American style, pp. 386-93 *in* Movement of highly mobile insects. Concepts and methodology in research. North Carolina State University, Raleigh, NC.

OATMAN, E. R., AND G. R. PLATNER. 1972. An ecological study of lepidopterous pests affecting lettuce in coastal southern California. Environ. Entomol. 1: 202-204.

PEARSON, A. C. 1982. Biology, population dynamics, and pest status of the beet armyworm (*Spodoptera exigua*) in the Imperial Valley of California. Ph.D. dissertation, Univ. of California, Riverside Calif.

POE, S. L., G. L. CRANE, AND D. COOPER. 1973. Bionomics of *Spodoptera exigua* Hüb., the beet armyworm, in relation to floral crops. Proc. Trop. Reg. American Soc. Hortic. Sci. 17: 389-396.

RUBERSON, J. R., G. A. HERZOG, AND W. J. LEWIS. 1993. Parasitism of the beet armyworm, *Spodoptera exigua*, in south Georgia cotton. Proc. 1993 Beltwide Cotton Prod. Conf. 3: 993-997.

RUBERSON, J. R., G. A. HERZOG, W. R. LAMBERT, AND W. J. LEWIS. 1994. Management of the beet armyworm: integration of control approaches. Proc. 1994 Beltwide Cotton Prod. Conf. 2: 857-859.

SMITH, R. H. 1989. Experiences with beet armyworm in cotton in 1988. Proc. 1989 Beltwide Cotton Prod. Conf., pp. 273-275.

SOTERES, K. M., R. C. BERBERET, AND R. W. MCNEW. 1984. Parasitic insects associated with lepidopterous herbivores on alfalfa in Oklahoma. Environ. Entomol. 13: 787-793.

SWEZEY, O. H. 1935. The winter revival of insect life in the arid region at Koko Head, Oahu. Proc. Hawaiian Entomol. Soc. 9: 93-96.

TINGLE, F. C., T. R. ASHLEY, AND E. R. MITCHELL. 1978. Parasites of *Spodoptera exigua*, *S. eridania* (Lep.: Noctuidae) and *Herpetogramma bipunctalis* (Lep.: Pyralidae) collected from *Amaranthus hybridus* in field corn. Entomophaga 23: 343-347.

TURLINGS, T. C. J., J. H. TUMLINSON, F. J. ELLER, AND W. J. LEWIS. 1991. Larval-damaged plants: source of volatile synomones that guide the parasitoid *Cotesia marginiventris* to the micro-habitat of its hosts. Entomol. exp. appl. 58: 75-82.

USDA-APHIS. 1991. National boll weevil cooperative control program. Final environmental impact statement - 1991. U.S. Govt. Printing Office, Washington DC.

VAN DEN BOSCH, R., AND K. S. HAGEN. 1966. Predaceous and parasitic arthropods in California cotton fields. Calif. Agric. Exp. Sta. Bull. 820. 32 pages.

WHITCOMB, W. H., AND K. BELL. 1964. Predaceous insects, spiders, and mites of Arkansas cotton fields. Agric. Exp. Sta., Univ. of Arkansas, Bull. 690. 84 pages.

WILKINSON, J. D., K. D. BIEVER, AND C. M. IGNOFFO. 1979. Synthetic pyrethroid and organophosphate insecticides against the parasitoid *Apanteles marginiventris* and the predators *Geocoris punctipes*, *Hippodamia convergens*, and *Podisus maculiventris*. J. Econ. Entomol. 72: 473-475.

WILSON, J. W. 1932. Notes on the biology of *Laphygma exigua* Hübner. Florida Entomol. 16: 33-39.

WILSON, J. W. 1933. The biology of parasites and predators of *Laphygma exigua* (Hübner) reared during the season of 1932. Florida Entomol. 17: 1-15.

WILSON, J. W. 1934. The asparagus caterpillar: its life history and control. Florida Agric. Exp. Sta. Tech. Bull. 271: 1-26.

WOLFENBARGER, D. A., AND M. J. BREWER. 1993. Toxicity of selected pesticides to field collected beet armyworm populations. Proc. 46th Beltwide Cotton Prod. Conf. 2: 1034-1035.