Inundative Release of *Archytas marmoratus* (Diptera: Tachinidae) Against the Corn Earworm and Fall Armyworm (Lepidoptera: Noctuidae) in Whorl-Stage Corn[1]

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Abstract A 3-yr pilot test was conducted to determine the feasibility of controlling early-season populations of corn earworm, *Helicoverpa zea* (Boddie), and fall armyworm, *Spodoptera frugiperda* (J. E. Smith), by augmentative releases of the tachinid parasitoid *Archytas marmoratus* (Townsend). Percentage parasitism of corn earworm larvae was increased to 42% in non-isolated fields of whorl-stage corn and >90% in isolated fields by inundative releases (≈1500 *A. marmoratus* ♀♀ per ha per week). Fall armyworm larvae were parasitized at a much lower level than corn earworm larvae. In a contiguous corn growing area, there was a positive correlation between density of corn earworm larvae and percentage parasitism within 0.8 km of the release field. The field with the greatest larval density and percentage parasitism of corn earworm larvae was the one farthest from the release site, indicating good host finding capability by *A. marmoratus.* These results show that inundative releases of this parasitoid could become an important component of integrated management strategies against early-season populations of corn earworm and fall armyworm. The high percentage of superparasitism in corn earworm larvae suggests that the release rate of *A. marmoratus* will need to be adjusted to host larval density.

Key Words Parasitoid, augmentation, biological control

Archytas marmoratus (Townsend) is a solitary larval-pupal parasitoid of several noctuids including the corn earworm, *Helicoverpa zea* (Boddie), and fall armyworm, *Spodoptera frugiperda* (J. E. Smith). Females of this species larviposit planidia on plants nearby host larvae. The planidia, or first-instar maggots of the parasitoid, attach themselves to host larvae upon contact (Hughes 1975). Planidia enter the host larva within a few hours but remain in the first stadium until after the host has pupated. Maggots develop rapidly, pupating within a few days, with adults eclosing ≈2 wk later. *Archytas marmoratus* may successfully parasitize second instars, but survival is greater when older larvae are attacked. Each time the host molts, *A. marmoratus* must exit its host and reenter following ecdysis. More than one plandium may enter a host larva but only one will complete development (Reitz 1995).

Archytas marmoratus has been collected from many crops including corn, cotton, tobacco, and soybean. Although considered to be more abundant in the late season (Bibby 1942, Boltrell et al. 1968, Shepherd and Sterling 1972), Gross et al. (1976)

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found *A. marmoratus* to be the only parasitoid attacking corn earworm in whorl-stage and early tassel-stage corn. Manley et al. (1991) observed 25% parasitism of corn earworm by *A. marmoratus* in whorl-stage corn in South Carolina and Smith et al. (1976) found *A. marmoratus* to be an important parasitoid of the corn earworm in whorl-stage corn in Mississippi.

The fall armyworm and corn earworm are the two most destructive insect pests of corn in the southeastern United States. Some pest managers believe that populations of corn earworms increase to damaging levels on corn, and then subsequently move into cotton, peanuts, soybeans, and vegetables (Kennedy et al. 1987).

Like many natural enemies, early-season population levels of *A. marmoratus* are inadequate to prevent the seasonal increase of corn earworms. Recently, H.R.G. initiated studies to determine the potential of managing corn earworms by inundative releases of *A. marmoratus* in whorl-stage corn. Mass production procedures were developed to mechanically extract maggots from fecund females (Gross and Johnson 1985) and to rear the parasitoid on a factitious host, the greater wax moth, *Galleria mellonella* L. (Lepidoptera: Galleriidae) (Bratti and Costantini 1991, Gross 1994, Gross et al. 1996). Preliminary studies of early-season *A. marmoratus* releases were promising (Gross 1988, 1990, Gross and Young 1984, Gross et al. 1985). Therefore, a 3-year pilot test was initiated in 1993 to examine the feasibility of controlling early-season populations of corn earworm and fall armyworm by augmentative releases of *A. marmoratus.* The results of this study are presented herein.

Materials and Methods

Methods of culturing *A. marmoratus* on *G. mellonella.* *Archytas marmoratus* has been maintained in culture since 1981, with intermittent infusion of genetic material from parasitized *H. zea* and *S. frugiperda* larvae collected from whorl-stage corn in Georgia or Florida. The colony has been maintained on larvae of *H. zea* from the Tifton, GA, laboratory colony (Young et al. 1976) according to the methods of Gross and Johnson (1985). *Heliocoverpa zea* larvae were reared on corn-soy-meal (CSM) artificial diet (Jones et al. 1977) using the methods of Burton (1969). *Archytas marmoratus* used for inundative field releases were mass propagated on *G. mellonella* as described by Gross (1994) with the following exceptions: containers used for rearing *G. mellonella* were cylindrical, 5.7-liter, Rubbermaid® Servin' Saver Salad Keeper (No. 3056) (Rubbermaid®, Wooster, OH). A circular opening (14.5 cm diam) was cut in the lid, and the entire inner lid surface was covered with aluminum screen (7-mesh per cm) to permit air exchange and prevent pupating larvae from damaging the lid.

The diet ingredients used to rear *G. mellonella* larvae were as follows: 286 g Gerber Mixed® cereal (Gerber®, Fremont, MI), 286 g Gerber HiProtein® cereal (Gerber®, Fremont, MI), 200 g wheat germ, 44 g torula yeast, 124 g sucrose, 264 ml glycerine, and 270 ml water. Dry ingredients were blended with a hand-held blender (Model KHM3WH) (Kitchen Aid®, St. Joseph, MI). *Archytas marmoratus* maggots were applied at a rate of ≈20 maggots per cm^2 (≈4 per cardboard cell opening) on top of cardboard disks (13 cm diam by 2 cm deep); 16 to 24 h later, mature larvae of *G. mellonella* (130 g, ≈600 larvae) were placed on top of each disk insuring that host larvae would contact maggots as they entered cells to pupate. The cardboard disks containing parasitized *G. mellonella* were placed in 1.3-liter Rubbermaid® containers during the 17 to 18-d developmental period. When *A. marmoratus* adults began to eclose, the cardboard disks were placed singly into 30 × 30 × 15 cm cardboard bakery

boxes (Albany Paper Supply, Albany, GA). Two 4 × 8 cm openings were cut on opposite sides of the box and covered with plastic or aluminum window screen (7 mesh per cm). Water-saturated cotton and sugar cubes as food were provided.

The boxes were held at 27 ± 1°C, 75 ± 5% RH and 1:23 (L:D) photoperiod. The limited photophase provided adequate light for mating (>90% of ♀♀ mated successfully), but restricted activity, preventing severe wing damage. Flies were held for 13 to 14 d before release; most females were ready to larviposit upon leaving the release boxes.

Field selection and release strategies. King et al. (1981) obtained higher levels of parasitism when *Lixophaga diatraea* (Townsend), a tachinid parasitoid of the sugarcane borer, *Diatraea saccharalis* (F.), was released in sugarcane fields surrounded by woodlands than when released in fields surrounded by more sugarcane. Therefore, in 1993 and 1994, corn fields (2-7.3 ha) were selected that were separated from each other by ≥8 km, isolated from other corn, and adjoining woodlands on at least two sides. Paired fields were selected based upon similar developmental stage of corn and randomly assigned as control or release. They were located in southern Georgia (Tift, Berrien, Irwin, or Worth Counties) and northern Georgia (Towns Co.) or southern North Carolina (Graham or Union Counties). In 1993, two pairs of fields were located in southern Georgia, two in northern Georgia and two in southern North Carolina. In 1994, five pairs of fields were located in southern Georgia and one pair in northern Georgia.

In 1995, *A. marmoratus* was released in one field (≈4 ha) in Irwin Co. (near Ocilla) and another field (≈4 ha) in Worth Co. (near Ty Ty). These fields were isolated from other corn and were bordered on one side by woodland and on the other sides by peanuts, cotton, or wheat. Additional releases were made in three areas surrounded by other corn fields to compare parasitism in release and surrounding fields (Fig. 1). Two of the study areas were in Berrien Co., GA: one in early-season corn, 9 km east of Alapaha, and the second in mid-season corn ≈2 km northwest of Nashville, GA. The third study area was in late-season corn located in northern Georgia 16 km south of Blairsville (Towns Co.). Although some fields in each study area were adjoining, others were separated by woodland. The size of the release fields, time of first release, and release rate for *A. marmoratus* for all years are shown in Table 1.

Bakery boxes containing *A. marmoratus* adults were transported to release fields within an enclosed cooled vehicle with darkened windows to restrict light. Gross et al. (1975) and Loke (1981) demonstrated that pre-release exposure of some parasitoids to host kairomones enhanced parasitoid retention in the release area and increased levels of parasitization. Nettles and Burks (1975) found that *A. marmoratus* reacted to kairomones in the frass of host larvae. Therefore, before *A. marmoratus* adults were distributed, 2 to 3 ml of a 10% aqueous solution of *H. zea* larval frass were sprayed through one of the screened openings into each box. The solution was prepared from frass collected from fifth-instar *H. zea* that had fed on blackeyed purple hull pea cotyledons.

Bakery boxes holding *A. marmoratus* were placed uniformly by hand throughout the fields along rows. The number of rows where boxes were placed varied depending on size and shape of the field. When the box was in position, the top of the box was cut along three sides and pulled open. The box was turned on its side allowing flies to exit. Empty boxes were removed from the fields the day of release because flies generally left the boxes within one hour.

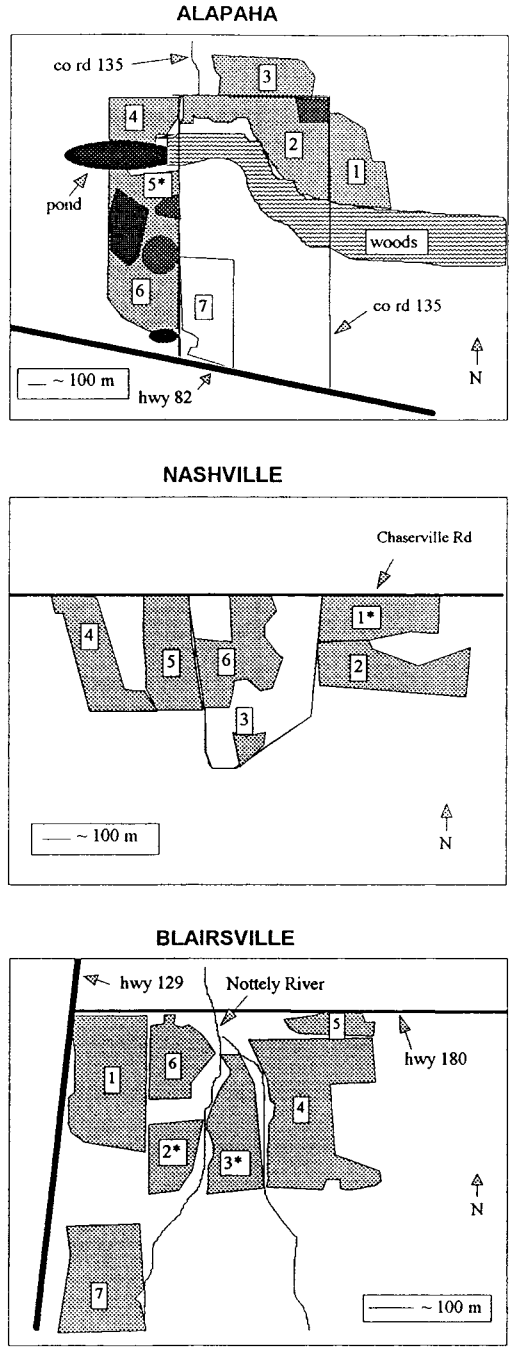

Fig. 1. Location of release field in relation to other study fields at Alapaha, Nashville, and Blairsville, GA during 1995. (Medium-dark shaded areas in the Alapaha map indicate the areas in which no corn was growing.)

Table 1. Release rates for *A. marmoratus* females in whorl-stage corn during the pilot test

Year	Field	Size (ha)	Date of 1st release	No. of wks released	♀♀ flies/ wk/ha
1993	T1*	6.5	11 May	3	1384
	T2*	4.4	11 May	3	1517
	T1**	2.4	3 June	6	1815
	T2**	2.0	10 June	3	1938
	T3†	2.4	3 June	4	1867
	T4†	6.5	3 June	3	1366
1994	T1*	4.9	2 May	3	1239
	T2*	4.4	2 May	2	1305
	T3*	7.3	2 May	2	1258
	T4*	3.6	20 May	3	1229
	T5*	2.8	20 May	3	1115
	T6**	6.5	23 June	1	1873
1995	Ocilla*	4.0	28 April	5	882
	Ty Ty*	4.0	28 April	5	1971
	Alapaha*	4.0	28 April	5	2023
	Nashville*	4.7	2 June	5	1890
	Blairsville**	4.2	7 July	5	1673

* Located in southern Georgia.
** Located in northern Georgia.
† Located in southern North Carolina.

Larval sampling procedure. Fields were sampled at weekly intervals. In 1993 and 1994, fields were divided into 40-row sections and *H. zea* larval density was estimated from two random samples of 100 plants from each field section. Subsequently, *H. zea* fourth and fifth instars were collected from nearly equal field sections. The sampler entered each section and scanned a total of six rows (three rows on each side) while looking for plants damaged by *H. zea* late instars. A total of four six-row swaths were searched in each section, and each six-row swath was separated by 4 rows. In fields with only a few *H. zea, S. frugiperda* also were sampled. Damaged plants within three rows were readily apparent. Approximately 45 min were required for the sampler to search each section of a field. Larvae were placed into 30-ml plastic cups with 10 to 12 ml of CSM diet and held in the laboratory until eclosion of parasitoid or host. Dead larvae and pupae were examined for *A. marmoratus*.

In 1995, the densities of corn earworm and fall armyworm larvae (≥third instar) were estimated from 2-m-row samples. There was 0.91 m between rows; therefore,

each sample area was 1.82×10^{-4} ha. Twenty 2-m samples were taken weekly per corner quadrant per field during the whorl stage, using the sampling program developed by Legg and Yeargan (1985). All fourth- and fifth-instar larvae found were collected and observed for parasitism as previously described. During the first sample, the number of plants in the sample unit also was determined. Additional late-instar larvae of corn earworm and fall armyworm were collected by scanning six rows at a time while walking end to end for ≈45 min per quadrant as previously described.

Data analysis. Frequency data were tested for homogeneity with a log likelihood ratio test (Sokal and Rohlf 1969). Data were pooled so that cell frequencies were ≥5. If cell frequencies were <5 when combined, data were analyzed by Fisher's 2-tailed, Exact Test (PROC FREQ, SAS Institute 1989). Maximum larval density per hectare and distance from release site were correlated with percentage parasitism using Pearson's correlation coefficients (PROC CORR, SAS Institute 1989). Data on number of maggots per host were analyzed by PROC NPAR1WAY (SAS Institute 1989).

Results and Discussion

Percentage parasitism following release. *1993 Tests.* In 1993, larval density of *H. zea* in all fields was low (whorl infestation was between 0.1% and 0.3%). Only 36 to 84 larvae were collected per field per sampling date. Inundative releases of *A. marmoratus* greatly increased the parasitism of *H. zea.* For example, the highest level of parasitism by *A. marmoratus* from any control field was 21%; whereas, the lowest level of parasitism from any release field was 84%. For all larvae collected combined, percentage parasitism in southern Georgia was ≤13% in control fields and ≥89% in release fields (Fig. 2). On 20 May, percentage parasitism of *H. zea* averaged 98% in release fields and 19% in control fields. One week later, these percentages were significantly lower (Fisher's exact probability ≤0.02): 90% and 6%, respectively.

At the northern location, *H. zea* larvae were found only in two release fields and three control fields. Parasitism levels following release of *A. marmoratus* were somewhat lower than in southern Georgia (Fig. 2). The *A. marmoratus* released in these fields were held for 6 to 8 h in transit and may have had a greater tendency to emigrate from the release area. Nevertheless, percentage parasitism of *H. zea* averaged 64% with no significant difference between release fields or samples within release fields ($G = 2.858$, df = 2, $P = 0.240$; one field sampled twice). In contrast, of 131 *H. zea* larvae collected in three control fields, only three were parasitized and two of these were from one field (field no. 2, $n = 11$).

Percentage parasitism of *S. frugiperda* was significantly lower than that of *H. zea.* Only 35% of 86 *S. frugiperda* larvae collected from three release fields (one in Tift Co., GA, and two in northern Georgia) contained *A. marmoratus;* parasitism levels among fields were similar (20 to 45%, n = 12-38, $P = 0.231$, Fisher's 2-tailed Exact Test). Only 2 of 44 *S. frugiperda* larvae collected from control fields in northern Georgia or North Carolina were parasitized. Pair et al. (1986) reported *A. marmoratus* as the primary parasitoid of medium and large *S. frugiperda* larvae in seven Atlantic or Gulf Coastal States and northeastern Mexico. Under controlled laboratory conditions, large larvae of *H. zea* are typically parasitized by *A. marmoratus* at a higher level than are *S. frugiperda* (HRG, unpubl. data). We have no data to indicate whether volatiles in the frass of *H. zea* are more attractive to *A. marmoratus* than are volatiles in the frass of *S. frugiperda.*

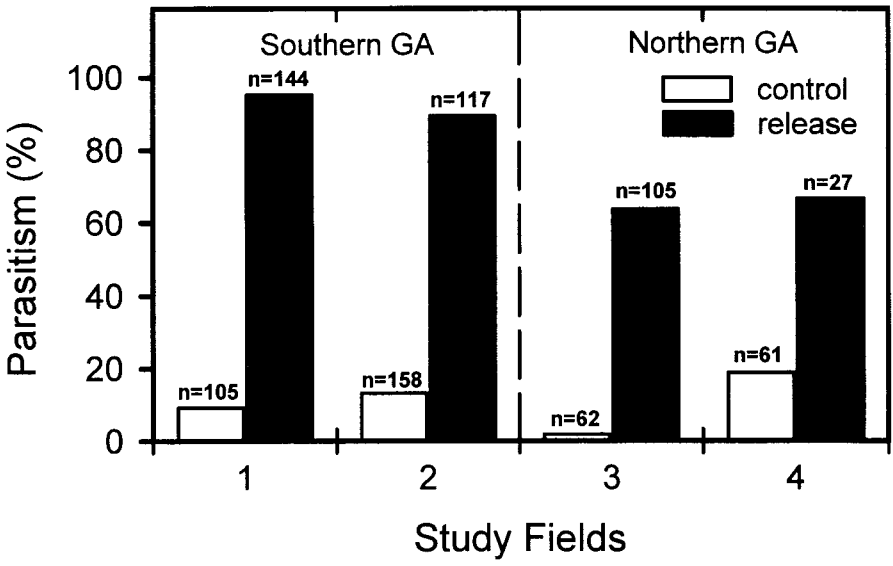

Fig. 2. Percentage parasitism of *H. zea* larvae in control and release fields in 1993 (release and control fields 1 and 2 located in southern Georgia; 3 and 4 located in northern Georgia or southern North Carolina).

1994 tests. In 1994, we observed unusually high levels of parasitism by *A. marmoratus* in three of four control fields in southern Georgia (42 to 65%) (Fig. 3). Too few larvae were collected in the fourth field to accurately assess parasitism. Still, parasitism of *H. zea* larvae from release fields was significantly greater than that for larvae from the corresponding control field for all pairs except field no. 2 ($G = 9.863$, df = 1, $P < 0.002$; or $P < 1.47 \times 10^{-4}$, Fisher's Exact Test). For the no. 2 pair 61% of the *H. zea* larvae collected from the control field and 70% from the release field were parasitized ($G = 2.843$, df = 1, $P = 0.092$). The high levels of parasitism in control plots in 1994 suggest a high level of overwintering survival of *A. marmoratus.* Overwintering strategies for *A. marmoratus* are not known but studies by Danks et al. (1979) suggest the parasitoid probably does not diapause. Winter temperatures were mild during 1993-1994; thus, greater than normal numbers of *A. marmoratus* may have survived the winter.

There was no significant difference in parasitism between samples from different sections within fields ($P > 0.311$, Fisher's Exact Test) or among control fields within the same week in 1994 ($P \geq 0.198$, Fisher's Exact Test). But parasitism varied significantly with week (Fig. 4). For the first week after release, 87% of the *H. zea* larvae collected from all fields were parasitized with no significant difference between control and release fields ($G = 0.581$; df = 1; $P = 0.446$). Thereafter, percentage parasitism of larvae from control fields was significantly lower than parasitism of larvae from release fields ($P \leq 1.08 \times 10^{-4}$, Fisher's Exact Test). Forty-six percent of the *S. frugiperda* collected ($n = 122$) were parasitized by *A. marmoratus* with no difference between release and control fields ($G = 4.226$, df = 4, $P > 0.1$).

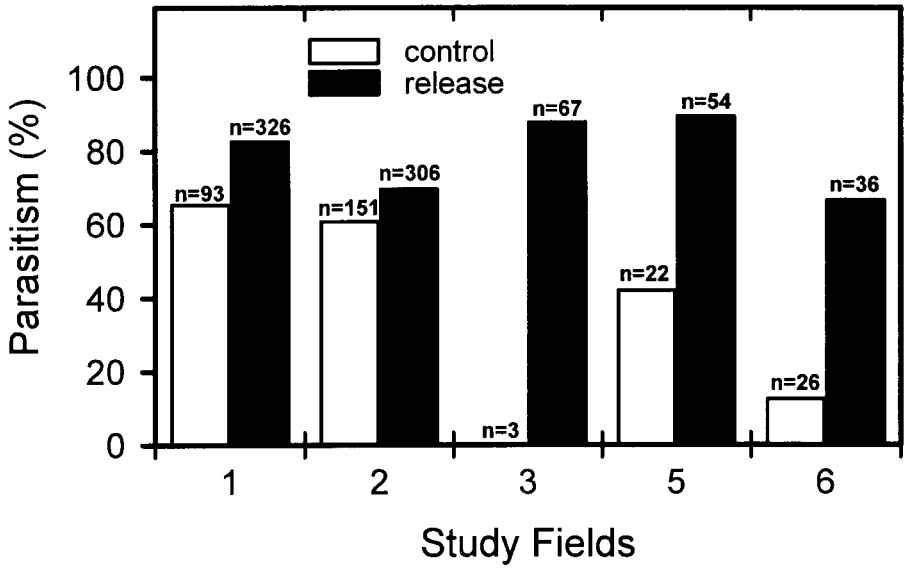

Fig. 3. Percentage parasitism of *H. zea* larvae in control and release fields in 1994 (1 through 5 located in southern Georgia, 6 located in northern Georgia).

1995 tests. In 1995, larval populations of *H. zea* on whorl-stage corn varied greatly among study areas. At the Ty Ty and Alapaha sites, average estimated larval density (≥third instar) varied from 68 to 273 larvae per ha for 4 wk during May (Table 2). The greatest number of larvae was sampled and the second week of May. The greatest estimated density for any week and field was 479 larvae per ha (field 1, Alapaha, 17 May). No *H. zea* larvae were found in 380 2-m-row samples (0.06 ha) from Ocilla or 890 samples (0.16 ha) from Nashville, indicating a larval population at these two locations of <14 and 6 larvae per ha, respectively. A few *H. zea* larvae were collected at both locations in samples to determine percentage parasitism. Only 4 *H. zea* larvae were found in 2495 2-m-row samples (0.45 ha) over a 5-wk period at Blairsville, equalling 9 larvae per ha.

Except for the Ocilla location, *S. frugiperda* larvae were found in 2-m-row samples from all locations and averaged from 2 to 340 larvae per ha for the sampling period (Table 2). At Alapaha, larval densities of *S. frugiperda* were similar to those of *H. zea*. At Nashville, 88% of the *S. frugiperda* larvae found were sampled the first week (30 May) with a maximum of 675 larvae per ha found in field 4.

In early corn, percentage parasitism of *H. zea* by *A. marmoratus* in release fields varied from 41 to 62% and that of *S. frugiperda* varied from 10 to 35% (Table 3). We observed a significant positive correlation between host larval density and percentage parasitism for *H. zea* from different fields at Alapaha ($r = 0.908$, $P = 0.012$). The field with the highest larval population and greatest percentage parasitism was also the one farthest from the release field.

Averaged over all fields, 15% of the *S. frugiperda* larvae from Alapaha were parasitized, with no difference in *S. frugiperda* parasitism among fields ($P = 0.293$,

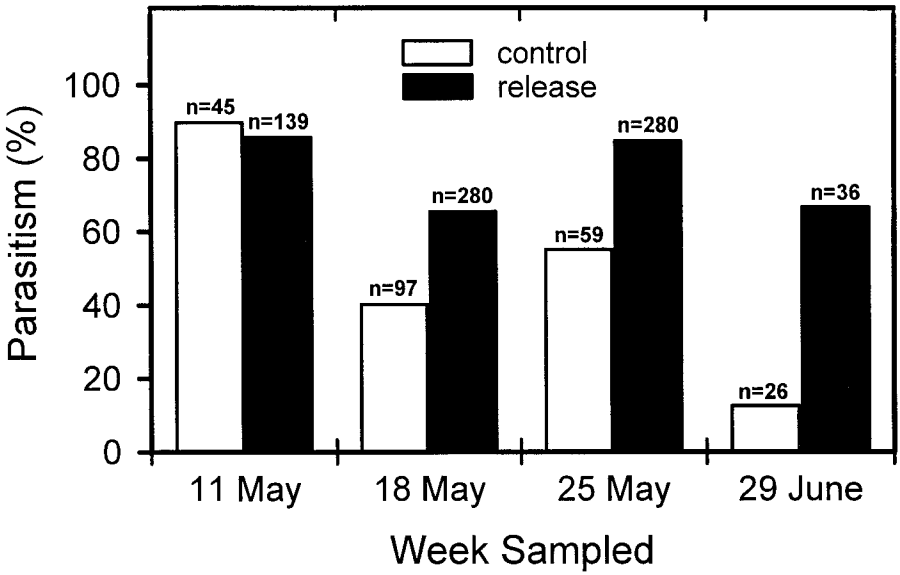

Fig. 4. Weekly parasitism levels of *H. zea* larvae in control and release fields in 1994, pooled over locations.

Fisher's Exact Test). In contrast, 35% of *S. frugiperda* larvae from Ty Ty were parasitized. A three-way G-test, species by location by parasitism, gave a highly significant value ($G = 63.929$, df = 4, $P < 0.001$); *H. zea* was parasitized at a greater level than *S. frugiperda* ($G = 57.215$, df = 1, $P < 0.001$). There was no significant species by location or parasitism by location effect ($G \leq 2.517$, df = 1, $P \geq 0.1$); but there was a nearly significant species by location by parasitism interaction ($G = 3.631$, df = 1, $P = 0.057$). Nonetheless, percentage parasitism of *H. zea* larvae with *A. marmoratus* between Ty Ty and Alapaha was similar ($G = 0.165$, df = 1, $P = 0.684$). Too few *H. zea* larvae were collected at Ocilla, Nashville, or Blairsville to accurately estimate percentage parasitism. Parasitism of *S. frugiperda* at Nashville (Table 4) and Blairsville (Table 5) was similar to that at Alapaha (parasitism $\approx$ 15%; $G = 1.535$, df = 2, $P = 0.464$).

Corn fields at Nashville and Blairsville were sampled before release of *A. marmoratus*. No *H. zea* larvae were found, and none of the *S. frugiperda* larvae collected were parasitized. Similarly, no *S. frugiperda* larvae collected from the control field at Blairsville were parasitized. Four *H. zea* larvae were collected following releases in Nashville and Blairsville, and three were parasitized. This suggests that *A. marmoratus* females are efficient in finding host larvae, even at low densities.

Superparasitism. The negative effect of large numbers of foraging *A. marmoratus* females was apparent by the poor survival of parasitized *H. zea* larvae collected from release fields. In 1993, only 38% of collected larvae ($n = 231$) pupated and 15% produced an adult fly. For larvae that died before pupation, the average number of maggots per larva was 5.5 (range, 1-20). Seven of ten parasitized larvae collected from control fields produced a fly. Further, all non-parasitized *H. zea* larvae pupated and 89% eclosed.

Table 2. Average number of *H. zea* and *S. frugiperda* per ha based on 2-m-row samples of whorl-stage corn during 1995

Location	Field no.	Field size (ha)	Total samples	*H. zea* avg ± SEM	*S. frugiperda* avg ± SEM
Ocilla*	1	4.0	380	<14	<14
Ty Ty*	1	4.0	320	68 ± 34.2	222 ± 81.1
Alapaha*	1	4.9	320	273 ± 71.0	222 ± 65.1
	2	13.9	320	171 ± 93.2	102 ± 42.4
	3	7.8	320	68 ± 34.0	137 ± 90.2
	4	4.6	320	120 ± 44.8	85 ± 38.0
	5	4.0	380	115 ± 40.3	101 ± 62.6
	6	7.4	320	222 ± 60.4	325 ± 72.3
Nashville**	1	4.7	162	<34	304 ± 128.9
	2	5.0	163	<34	101 ± 57.7
	3	1.4	81	<67	67 ± 67.5
	4	6.8	161	<34	340 ± 150.0
	5	4.2	162	<34	135 ± 66.9
	6	5.5	161	<34	204 ± 81.9
Blairsville†	1-7	20.8	2495	9 ± 4.4	2 ± 2.2

* Sampled weekly for 4 weeks beginning 1 May.
** Sampled weekly for 2 weeks beginning 30 May.
† Sampled weekly for 5 weeks beginning 16 June.

Only 53% of parasitized *H. zea* ($n = 659$) collected in 1994 from release and control fields produced *A. marmoratus* adults. Of 81 dead, parasitized *H. zea* larvae that were dissected, all but nine were superparasitized. Average number of maggots per larva was 6.3 (range, 1 to 20). Of 19 dead *H. zea* pupae dissected, only two were superparasitized; each contained two maggots. Ninety percent of the non-parasitized larvae collected from all fields eclosed as adults.

In 1995, the number of maggots in *H. zea* larvae were counted by inspecting the area below the integument of each larva. The average number of maggots per larva was 3.5 ($n = 128$; range of 1 to 20). Only one fly emerged from a superparasitized larva and none emerged if more than 4 maggots were present (Fig. 5). At Alapaha, we found no significant difference in superparasitism among fields (Fisher's Exact Test, $P = 0.546$). Likewise, we found no significant difference in the frequency of superparasitism between larvae collected from Alapaha and those from Ty Ty (Fisher's Exact Test, $P = 0.216$; 70% were superparasitized). Further, the average number of maggots per larva was statistically similar (mean = 3.4, $F = 0.869$, $P = 0.353$; PROC NPAR1WAY, SAS Institute [1989]). However, the average number of maggots per larva was 7.5 (range of 3 to 19) from four dissected *H. zea* that were collected from

Table 3. Field size and plant density of release and control fields, number of *H. zea* and *S. frugiperda* larvae sampled, and percentage parasitized by *A. marmoratus* when released in whorl-stage corn in southern GA during 1995

Locale	Field	Field size (ha)	Plants /ha ($\times 10^4$)	*H. zea*		*S. frugiperda*	
				no.	%	no.	%
Ocilla	1*	4.0	54.6	4	50.0	8	25.0
Ty Ty	1*	4.0	61.5	21	61.9	17	35.3
Alapaha	1	4.9	45.2	46	71.7	49	14.3
	2	13.9	48.2	41	58.5	1	100
	3	7.4	48.4	5	40.0	0	
	4	4.6	48.4	17	52.9	0	
	5*	4.0	57.6	24	41.7	20	10.0
	6	7.4	54.6	85	55.3	31	12.9
	7	24.3		5	60.0	14	21.4

* Release fields for *A. marmoratus*.

Table 4. Field size and plant density of release and control fields, number of *H. zea* and *S. frugiperda* larvae sampled, and percentage parasitized by *A. marmoratus* when released in whorl-stage corn near Nashville, GA during 1995

Field	Field size (ha)	Plants /ha ($\times 10^4$)	*H. zea*		*S. frugiperda*	
			no.	%	no.	%
1-6*			0		19	0
1**	4.7	31.6	0		14	7.1
2	5.0	33.8	0		5	40.0
3	1.4	30.6	0		0	
4	6.8	36.1	2	50.0	11	0
5	4.2	34.3	1	100	44	11.4
6	5.5	28.4	0		20	20.0

* Pre-release sample.
** Release field for *A. marmoratus*.

Table 5. Field size and plant density of release and control fields, number of *H. zea* and *S. frugiperda* larvae sampled, and percentage parasitized by *A. marmoratus* when released in whorl-stage corn in northern GA during 1995

Field	Field size (ha)	Plants /ha ($\times 10^4$)	*H. zea*		*S. frugiperda*	
			no.	%	no.	%
1-7*			1	0	8	0
control	2.0	38.8	0		17	0
1	3.5	47.4	0		0	
2**	1.3	49.4	0		6	16.7
3**	2.8	46.0	1	100	8	37.5
4	4.4	44.7	0		10	20.0
5	1.1	34.1	0		2	0
6	1.7	40.8	1	100	11	18.2
7	3.6	34.1	0		0	

* Pre-release sample.
** Release fields for *A. marmoratus.*

study sites with very low *H. zea* larval density (Ocilla, Nashville, and Blairsville). None of these produced an adult fly. Thus, it would appear that the intensity of superparasitism may depend to some degree upon parasitoid release rate and host larval density.

Only 22% of *S. frugiperda* larvae were superparasitized (mean number of maggots per larva = 1.4; n = 32; range of 1 to 6). As with *H. zea,* only one fly eclosed from superparasitized larvae. No flies eclosed from the two *S. frugiperda* larvae which contained more than two maggots.

Knipling (1992) estimated that 96% of the F_2 seasonal generation of *H. zea* would be expected to be parasitized by *A. marmoratus* if at least 89% of the F_1 generation was parasitized. Our data from 1993, suggest that the number of *A. marmoratus* adults produced from highly parasitized *H. zea* of the seasonal F_1 would be far lower than estimated by Knipling because of superparasitism. In our case, the relatively high density of *A. marmoratus* adults in the presence of low host densities apparently provided an opportunity for parasitoid females to encounter previously parasitized hosts. As suggested by Knipling (1992), the encounter of parasites with previously parasitized hosts represents a complete loss of host parasitization efficiency. Because *A. marmoratus* produces an abundance of progeny (1800 to 2800 maggots per female) and deposits them near host larvae, the need for discrimination between parasitized and non-parasitized hosts would not be as critical as parasitoids with limited fecundity that deposit individual eggs on or within the host. However, too many maggots prevent eclosion of the parasitoid as well as the host (Hughes 1975).

These studies show that inundative releases of *A. marmoratus* increased parasitism of corn earworm larvae in non-isolated as well as isolated fields. Corn earworm

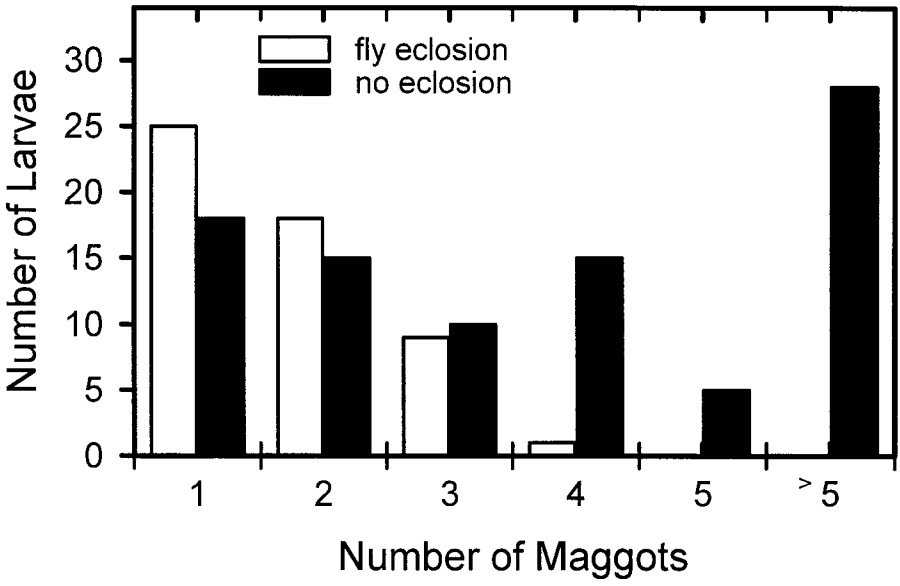

Fig. 5. Eclosion of *A. marmoratus* from parasitized corn earworm larvae collected from corn in 1995 in relation to number of maggots per host.

larvae were more heavily parasitized than were fall armyworm larvae. Thus, as suggested by Knipling (1992), inundatively released *A. marmoratus* are capable of playing a primary role in suppressing the incipient seasonal generation of *H. zea* in early-season corn. However, data from our releases also suggest that high levels of superparasitism by *A. marmoratus* and the death of a sizable portion of the incipient seasonal generation of *H. zea* will result in a low rate of *A. marmoratus* adult emergence in the F_2 generation. Because of the high level of superparasitism observed in release plots, the release rate (parasitoid to host larvae) was probably too high. Thus, to optimize inundative releases of *A. marmoratus* against *H. zea,* the release rate according to host larval density should be adjusted.

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