Bionomics of the Fall Armyworm (Lepidoptera: Noctuidae) and Its Ectoparasitic Nematode, *Noctuidonema guyanense*, in South Georgia[1]

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ABSTRACT The fall armyworm, *Spodoptera frugiperda* (J. E. Smith), is a perennial immigrant pest of several crops in south Georgia. Moths of *S. frugiperda* commonly are infested by an ectoparasitic nematode, *Noctuidonema guyanense* Remillet and Silvain in the Southeast. The seasonal chronology and natural association of these species are reported for Tift Co. from 1988 to 1994. Seasonal influxes of non-infested moths usually arrive in late April and dissipate in early November. Seasonal influxes of infested male moths follow the initial immigrants by 4 to 6 wks and disappear in the fall from 1 to 2 mos earlier than the general moth populations. Feral male moths that are moderately worn and infested by *N. guyanense* weigh less than moderately worn, non-infested males. *Noctuidonema guyanense* infests moths of several species of noctuids, but it has not been found on the cotton bollworm/corn earworm [*Helicoverpa zea* (Boddie)], tobacco budworm [*Heliothis virescens* (Fab.)], or beet armyworm [*S. exigua* (Hübner)].

KEY WORDS *Spodoptera frugiperda*, Lepidoptera, Noctuidae, *Noctuidonema guyanense*, Nematode, Acugutturidae

The fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera: Noctuidae), is a perennial migratory species whose populations are replenished in south Georgia each spring from overwintering habitats in south Florida (Sparks 1979, Pair et al. 1986, Mitchell et al. 1991). The moth stage of the fall armyworm is infested by an obligatory ectoparasitic nematode, *Noctuidonema guyanense* Remillet and Silvain (Nematoda: Acugutturidae). Because all stages *N. guyanense* develop and occur only on the moth stage of its host (Rogers et al. 1991), its population also must be replenished in south Georgia each spring by infested moths immigrating from overwintering habitats. This study was designed to delineate population trends for the fall armyworm and *N. guyanense* in south Georgia. We also studied the relationship among scale wear of host moths, their body weight, and infestation by *N. guyanense*, and surveyed other species of noctuid pests for infestation by *N. guyanense*.

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Materials and Methods

Seasonal trend. Four widely-dispersed universal moth traps (International Pheromone Systems, Merseyside, England) baited with rubber septa impregnated with commercially-available sex pheromones (Raylo Chemicals Ltd., Edmonton, Canada and Scentry, Inc., Buckeye, AZ) were monitored throughout the year in Tift Co., GA, during 1991-1993. Moths were collected from the traps three to four times weekly and counted. The mean number of moths captured per trap per night was computed, and a three-night running average for the number of moths captured each year was determined. A subsample of the moths captured in pheromone traps was used to determine the percentage of the moths infested by *N. guyanense* each year. Percentage of moths harboring *N. guyanense* also was converted to a three-night running average for graphing purposes. Records were kept on the date of first and last detection each year for both the fall armyworm and *N. guyanense*.

Moth condition. A subsample of live moths removed from pheromone traps the morning following their capture in 1988 was transported to the laboratory where moths were weighed, evaluated for scale wear (loss of scales on forewings), and examined under a stereomicroscope to determine their infestation status. Infested moths were subjectively rated for scale wear on their forewings as none (pristine moths; no evidence of scale loss), slight (fresh, but showing some scale loss on forewings), moderate (obvious scale loss, but pattern on forewings still visible), and severe (absence of a scale pattern on forewings). Differences between the mean weight of infested and non-infested moths within each scale wear category were analyzed by a *t*-test using the Statistical Analysis System (SAS Institute 1989).

Nematode alternate hosts. Moths of a wide variety of species were captured in 1989-1994 by a 115-watt UV light trap mounted above a walk-in cage, 1.3 m × 1.3 m × 2.3 m, so that trapped moths fell into the cage. Live moths were collected from the interior of the cage and transported to the laboratory and identified by using the keys of Covell (1984) and Kimball (1965). Moths were examined under a stereomicroscope to determine their infestation status. Infested moths were quick-killed in a jar charged with ethyl acetate. Abdomens were immediately excised and placed in 2% formalin. The number of nematodes harbored on their abdomen was then counted under a stereoscopic microscope and recorded.

Results and Discussion

Seasonal trend. Male fall armyworm moths may be captured in pheromone traps in Tift Co. any month of the year in most years (Simmons et al. 1991). However, distinct influxes of moths indicating northerly migration from overwintering areas usually are detected in south Georgia after the middle of April (Table 1). Our data are consistent with those previously reported by Pair et al. (1986). An unusually large influx of moths on 4 April 1991, is thought to have resulted from the unseasonably warm spring in that year (Anonymous 1991). In 1994, failure to trap moths until 31 May was due to the use of an improperly formulated commercial batch of the fall armyworm sex pheromone. Although

Table 1. Seasonal influx and disappearance of feral male fall armyworm moths and *Noctuidonema guyanense* at Tifton, GA.

Year	Date moths detected		Date *N. guyanense* detected	
	First	Last	First	Last
1988	April 20	December 8	May 25	October 15
1989	May 28	December 7	May 28	October 12
1990	April 18	November 23	May 13	October 23
1991	April 4	December 19	April 8	November 10
1992	April 27	December 1	June 22	November 23
1993	May 6	December 15	June 21	October 18
1994	May 31*	October 21	May 31	October 21

* An improperly formulated sex pheromone prevented capture of moths prior to 31 May.

moths arrived early in Tift Co. in 1991, populations remained relatively low spring through fall, peaking at an average of 35 males captured per trap per night in mid-August (Fig. 1). In 1992, male populations peaked at an average of 128 moths per trap per night on 26 August. Maximum populations of moths caught in pheromone traps peaked at an average of 96 moths per trap per night on 21 October in 1993.

The propensity for *S. frugiperda* to achieve maximum population density from late summer through fall outside its overwintering habitats undoubtedly is attributed to the availability of atmospheric transport systems (e.g., the Bermuda High, which is responsible for a strong southerly flow of wind through the Southeast in the spring and early summer) (Pair and Westbrook 1995).

When moth influxes occurred in Tift Co. in late April, the first detection of *N. guyanense* followed the first detection of *S. frugiperda* by 4 to 6 wks (Table 1). When moth influxes occurred in early April or late May, first nematode detection coincided with moth immigration. The delayed appearance of *N. guyanense* indicates that the first seasonal influxes of moths are long-range migrants that are relatively free from nematode infestation, and that the appearance of the nematode in south Georgia coincides with the appearance of the second generation of *S. frugiperda* adults. For example, relatively few moths arriving in April harbor nematodes. In 1991, moths captured in April harbored an average of only 4 nematodes per host, compared with an average of 33 to 88 per host for moths captured from June through September.

By late June in 1991-1993, from 67 to 73% of the male fall armyworm moths harbored *N. guyanense* (Fig. 2). In 1993, 100% of the captured male moths were infested with *N. guyanense* on Julian dates 183 and 208. Up to 70% of the male moths were infested in late August and September in 1991 and 1993.

We suspect that some unknown threshold population of *N. guyanense* impedes flight of infested moths (Silvain and Remillet 1993). The nematode populations harbored by captured wild moths averages 30 to 50 specimens per host;

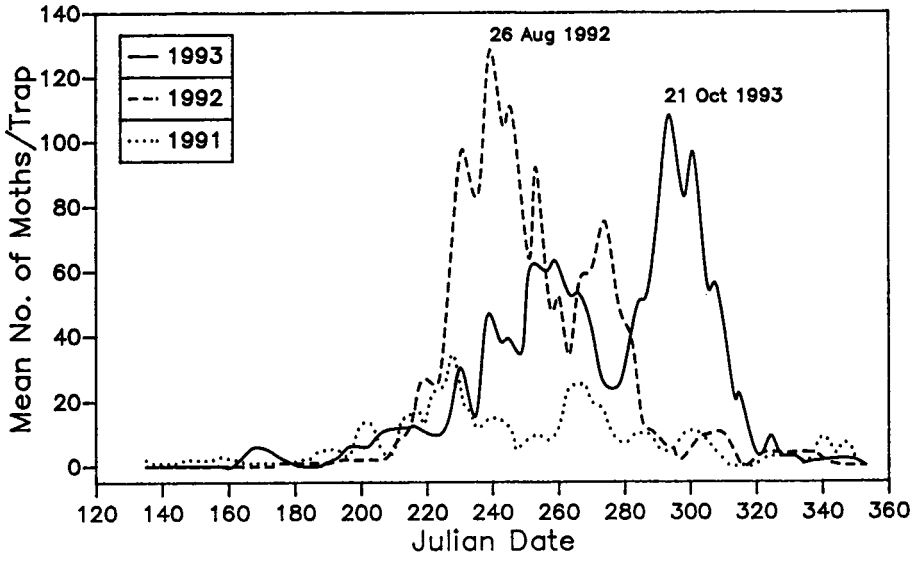

Fig. 1. Three-night running average for the number of *S. frugiperda* males captured in pheromone traps in Tift Co., GA (1991-1993).

whereas, in the laboratory, nematode populations of several hundred specimens per host are obtained after several days of incubation (Simmons and Rogers 1990, Rogers and Marti 1992). Since *N. guyanense* is chronically pathogenic to *S. frugiperda* (Marti et al. 1990), it is possible that heavy infestation (≅ 400-500 nematodes) may render feral moths incapable of flight; hence, their absence in standard pheromone traps.

Pair et al. (1987) and Mitchell et al. (1991) hypothesized that the fall armyworm has a southerly migration in the fall. The precipitous decline of nematode populations 1 to 2 months before moth populations crash in late fall supports such a fall migration theory for *S. frugiperda.* Non-infested moths from more northerly latitudes moving southward in the fall may account for the decline and disappearance of the nematode in south Georgia each fall before the fall armyworm becomes inactive.

Moth condition. Scale loss on moths may be used as a subjective assessment of their relative age and/or physical condition. Evaluation of 204 male moths captured in pheromone traps indicated that as scale loss increases, body mass declines. Nevertheless, captured moths exhibiting moderate scale loss and infested by *N. guyanense* weighed significantly less ($P < 0.05$) than similar moths not infested (Fig. 3). Across all scale loss categories, infested moths weighed significantly less ($P < 0.01$) than non-infested moths. Whether infestation by *N. guyanense* causes scale loss or the loss of body mass was not determined, but there was significant positive correlation between scale loss and infestation by *N. guyanense* ($r = 0.90$; $P < 0.01$). A reduction in body mass in

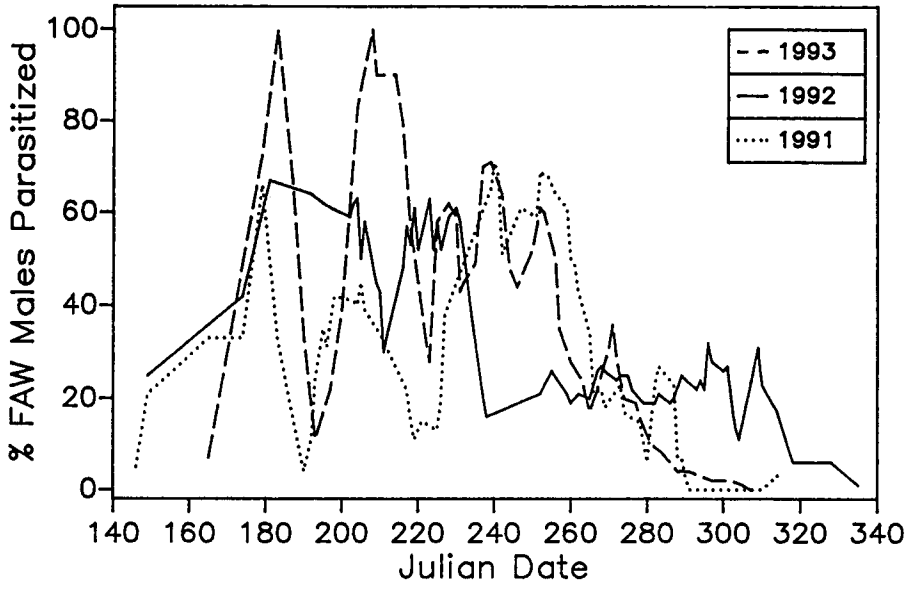

Fig. 2. Three-night running average for percentage of feral fall armyworm (FAW) male moths infested by *N. guyanense* in Tift Co., GA (1991-1993).

infested moths may indicate an energy drain that adversely affects the ability of aging moths to maintain sustained flight. Silvain and Remillet (1994) reported that there is a significant positive correlation between fat body depletion in infested female moths and the number of spermatophores they harbor. However, one may presume that these factors also may be influenced by moth age. In 204 infested male moths, there was a significant ($P = 0.01$) χ^2 relationship between fresh/worn moths and their infestation status. Also, fresh moths weighed more ($P = 0.05$) than worn moths, and non-infested moths weighed more ($P = 0.05$) than infested moths. However, the effects of these parameters on moth weight have not been clearly delineated at this time.

Nematode alternate hosts. Typically, from seven to nine pest species of Noctuidae harbor *Noctuidonema* each year in Tift Co. (Table 2). While most noctuid species are not hosts for *N. guyanense* in the wild (Rogers et al. 1990), manual infestation of some species has been possible in the laboratory. For example, successful recovery of *N. guyanense* manually transferred from *S. frugiperda* to *S. frugipersa, S. exigua* (Hübner), and *S. ornithogalli* occurred in 3 of 21 (14.3%), 8 of 17 (47.1%), and 1 of 8 (12.5%) attempts, respectively, in 1989. More recently, successful manual transfer of *N. guyanense* from *S. frugiperda* to *S. exigua* occurred in 77% of the attempts, resulting in their establishment and reproduction (Rogers and Marti 1995). Unsuccessful recovery of *N. guyanense* transferred from *S. frugiperda* occurred with *Helicoverpa*

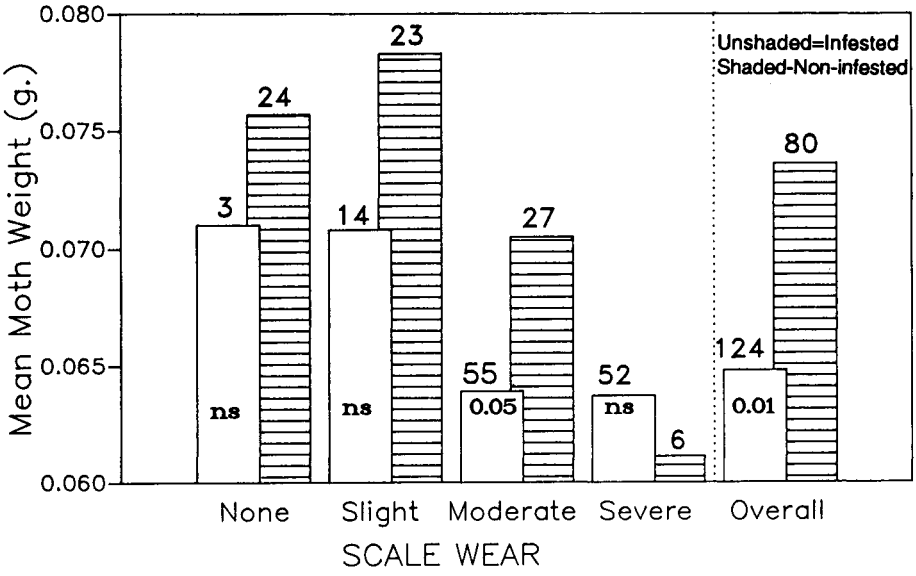

Fig. 3. Relationships among feral male *S. frugiperda* body weight, scale wear, and infestation by *N. guyanense*.

zea (Boddie) (31 attempts), *Heliothis virescens* (Fab.) (20 attempts), and *A. infecta* (2 attempts). Recovery of *N. guyanense* transferred from *S. ornithogalli* to *S. frugiperda* and *H. zea* occurred in 1 of 9 (11.1%) and 2 of 11 (18.2%) attempts, respectively. Recovery of *N. guyanense* transferred from *S. latifascia* to *S. frugiperda, S. exigua* and *H. zea* were successful in 3 of 7 (42.3%), 0 of 2, and 1 of 4 (25%) attempts, respectively. Egg production by *N. guyanense* females occurred following their transfer from *S. frugiperda* to *S. frugiperda, S. frugiperda* to *S. exigua, S. latifascia* to *S. frugiperda,* and *S. ornithogalli* to *S. frugiperda.* Recovery of *Noctuidonema* transferred from *M. latipes* to *S. frugiperda* failed in three attempts.

The *Noctuidonema* infesting *M. latipes* recently has been described as a new species (Marti and Rogers 1995). The recent descriptions of *N. dibolia* Marti and Rogers from *N. latipes* and *N. daptria* Anderson and Laumond from *Lesmone porcia* (Stoll) indicates that speciation of *Noctuidonema* may vary by host species (Anderson and Laumond 1992, Marti and Rogers 1995), and that additional *Noctuidonema* species may be described as we learn more about this ectoparasitic nematode of noctuid moths.

Typically, as in French Guiana (Silvain and Remillet 1993), *Noctuidonema* spp. infests moths of armyworms in south Georgia (Table 2). Species for which moths (number examined) were negative for nematodes in Tift Co. included *Acronicta* sp. (1), *Agrapha oxygramma* (Geyer) (12), *Agrotis malefida* Guenée (1),

Table 2. Economically important noctuid moths examined for *Noctuidonema guyanense* in Tift County, Georgia, March-October 1989-1994.

Species	No. moths examined	Moths infested	
		No.	%
Agrotis ipsilon (Hufnagel)	40	0	0
Agrotis subterranea (Fabricius)	85	0	0
Anicla infecta (Ochsenheimer)	48	5	10.4
Anticarsia gemmatalis (Hübner)	21	0	0
Helicoverpa zea (Boddie)	42	0	0
Heliothis virescens (Fabricius)	21	0	0
Mocis disseverans (Walker)	3	0	0
Mocis latipes (Guenée)*	74	240	41.8
Mocis spp.**	51	24	48.0
Pseudaletia unipuncta (Haworth)	154	1	0.6
Pseudoplusia includens (Walker)	13	0	0
Spodoptera dolichos (Fabricius)	24	2	8.3
Spodoptera eridania (Cramer)	18	0	0
Spodoptera exigua (Hübner)	97	0	0
Spodoptera frugiperda (J. E. Smith)	336	112	33.3
Spodoptera latifascia (Walker)	230	41	17.8
Spodoptera ornithogalli (Guenée)	226	39	17.3
Trichoplusia ni (Hübner)	9	0	0

* Nematode on *M. latipes* subsequently described as *N. dibolia* n. sp.
** *M. marcida* (Guenée) and/or *M. texana* Morrison.

Amolita fessa Grote (1), *Apatelodes torrefacta* (J. E. Smith) (3), *Argyrogramma verucca* (Fabricius) (15), *Catocala* sp. (2), *Caenurgina erechtea* (Cramer) (4), *Condica confederata* Grote (1), *Ctenucha virginica* (Esper) (2), *Datana* sp. (22), *Desmia funeralis* (Hübner) (1), *Diastema tigris* Guenée (1), *Diphthera festiva* (Fabricius) (2), *Dysgonia smithii* (Guenée) (1), *Ecpantheria scribonia* (Stoll) (1), *Elaphria chalcedonia* (Grote) (5), *Epimecis hortaria* (F.) (1), *Elaphria chalcedonia* (Grote) (5), *Epimecis hortaria* (F.) (1), *Estigmene acrea* (Drury) (1), *Furcula* sp. (3), *Galleria melonella* (L.) (1), *Heterocampa obliqua* Packard (1), *Lapara coniferarum* (J. E. Smith) (1), *Leucania* sp. (44), *Leuconycta diphteroides* (Guenée) (1), *Megalopyge opercularis* (J. E. Smith) (1), *Nadata gibbosa* (J. E. Smith) (1), *Ogdoconta cinereoa* (Guenée) (2), *Orthodes crenulata* (Butler) (6), *Panopoda* sp. (5), *Peridroma saucia* (Hübner) (2), *Phosphilia miselioides* (Guenée) (1), *Platysenta sutor* (Guenée) (7), *Plusiodonta compressipalpis* Guenée (1), *Prolimacodes badia* (Hübner) (1), *Schinia rivulosa* (Guenée) (4), *Symmerista albifrons* (J. E. Smith) (2), *Syntomeida ipomoeae* (Harris) (1), *Utetheisa bella* (L.) (2), *Xanthopastis timais* (Cramer) (1), and *Zale* sp. (6).

In summary, seasonal influxes of migrating male moths of the fall armyworm usually arrive in Tift Co. in late April and dissipate in early November. Influxes of moths infested by *N. guyanense* follow the initial arrival of moths by 4 to 6 wks and disappear from 1 to 2 mos before the total moth population crashes in the fall. Feral male moths that are moderately worn and infested by *N. guyanense* weigh less than males that are moderately worn and not infested. *Noctuidonema guyanense* infests several species of noctuids in south Georgia, but it had not been found on cotton bollworm, tobacco budworm, or beet armyworm moths.

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