

THE ROLE OF POPULATION DYNAMICS IN THE DEVELOPMENT OF CONTROL STRATEGIES FOR ADULT *HELICOVERPA ZEA*<sup>1</sup> AND OTHER NOCTUIDAE<sup>2</sup>

J. R. Raulston, S. D. Pair<sup>3</sup>, P. D. Lingren<sup>4</sup>  
W. H. Hendrix III<sup>5</sup>, and T. N. Shaver<sup>4</sup>

U. S. Department of Agriculture, Subtropical Agricultural Research  
Laboratory, Crop Insects Research Unit,  
2413 East Highway 83, Weslaco, Texas 78596

## ABSTRACT

This review discusses the characteristics of the regional population dynamics of *Helicoverpa zea* (Boddie) populations in relation to the seasonal availability of host plants. Although *Helicoverpa* populations developing on wild host plants characteristic of given regions may provide the inoculum for infestations on crop hosts, the crop hosts are most important in the development of large and damaging populations. Based on seasonal population development, several "windows" are described where manipulation of adult populations with chemical attractants from plants (phytoattractants) may be possible. Attracted moths could be killed with feeding-baits containing pesticides, thereby suppressing adult populations that result in subsequent larval infestations on crops.

## INTRODUCTION

The advantages of suppressing populations of the highly mobile noctuid moths have long been recognized. Although attempts to develop control procedures for *Helicoverpa* spp. adults have been somewhat disappointing, the concept has merit. Such research dates back at least to the mid-1850's when Glover (1855, 1865) recommended using poisoned vinegar and molasses baits to attract and kill adult corn earworms, *Helicoverpa zea* (Boddie). Attempts to control adult *H. zea* with feeding baits applied as bait stations, sprays, and by other methods were subsequently conducted (Malley 1893, Quaintance and Brues 1905, Ditman 1937, Lincoln et al. 1966), with varying degrees of success. These studies used feeding stimulants as classified by Hedin et al. (1974). There is little information available on phytoattractants for *H. zea* adults. Indeed, of more than 100 compounds listed as insect attractants, or kairomones, produced by plants (Hedin et al. 1974, Metcalf 1987), only

---

<sup>1</sup>Lepidoptera: Noctuidae

<sup>2</sup>Mention of a proprietary product does not constitute endorsement by the U. S. Department of Agriculture.

<sup>3</sup>USDA, ARS, South Central Agricultural Research Laboratory, P.O. Box 159, Hwy. 3 West, Lane, OK 74555.

<sup>4</sup>USDA, ARS, SCRL, APMRU, College Station, TX 77845.

<sup>5</sup>Dowelanco, 2800 Mitchell Drive, P. O. Box 9002, Walnut Creek, CA 94598-0902.

phenylacetaldehyde was designated for adult *H. zea*, several attractants were listed for other Lepidoptera. Because of the lack of information on plant produced kairomones for *H. zea*, projections of their possible use in manipulating adult populations must be considered hypothetically.

## REGIONAL PATTERN OF *H. ZEA* POPULATION DEVELOPMENT

The development of technology to manipulate populations of adult insects with kairomones requires an in-depth knowledge of the insect's ecology, behavior, and the processes that affect its population dynamics. The following review briefly discusses reports of the seasonal development of *H. zea* populations in several regions of the southern U.S. and identifies possible opportunities for using phytoattractants to suppress adult populations. Rabb (1979) listed three general characteristics of population dynamics and ecology that apply to many noctuid pests: (1) the adults are primarily nectar feeders and are often found in plant communities different from those where eggs are deposited; (2) they are multivoltine and use a succession of host plants for both adult and larval feeding; and (3) the food biomass is largely comprised of vast acreage of cultivated crops. Rabb (1979) also observed that the seasonal temporal and spatial shifts in pest populations are primarily along avenues of artificially expanded host plant biomass modified by the attractiveness of various hosts at a given time. Fitt (1989) listed four characteristics of *Heliothis/Helicoverpa* that equip them for exploitation of agro-ecosystems: (1) they are highly polyphagous and utilize a variety of cultivated and non-cultivated hosts as food sources; (2) the adults are highly mobile, a characteristic which facilitates their use of seasonal habitats across the range of their distribution; (3) their populations undergo a facultative diapause that facilitates survival during periods unfavorable for reproduction; and (4) they are highly fecund, allowing for rapid population increases.

The development of *Heliothis/Helicoverpa* populations follow temporal and spatial patterns that fit generalized regional frameworks. Initial adult populations are derived from overwintering and/or immigrating individuals and can occur before the availability of attractive cultivated host plants. These populations utilize a variety of wild host plants, usually characteristic for a given region, as food sources and reproductive sites.

The seasonal availability and role of various wild host plants in *Heliothis/Helicoverpa* population dynamics on a regional basis was reviewed by Stadelbacher et al. (1986). Although high density populations are normally associated with cultivated hosts, development on non-cultivated hosts is important in population maintenance before and after cultivated crops are available. In the Mississippi Delta of the southern U. S. A., moth activity in the spring preceded the availability of agricultural hosts by about 1.5 months. *Heliothis/Helicoverpa* reproduced on non-cultivated hosts and this population provided the inoculum for infestations that subsequently developed on cultivated hosts when they became reproductively attractive (Stadelbacher et al. 1986). In the presence of cultivated hosts, the role of native hosts in population maintenance and development is diminished or obscured because of the overwhelming biomass associated with the crop host. Although most *H. zea* were produced on corn in North Carolina, Neunzig (1963) concluded that on a per plant basis, larval population intensity on toadflax was equivalent to that on corn. Stinner et al. (1982) reported that >90% of the first two generations of *H. zea* in North Carolina were produced on corn. In the Lower Rio Grande Valley of Texas, both *H. zea* and *Heliothis virescens* F. were more abundant on early planted cultivated crops including tomato, lettuce, and corn, than on native weed hosts such as wild tobacco (Graham and Robertson 1970, Graham et al. 1972).

Following the appearance of cultivated hosts, development of *Heliothis/Helicoverpa*

populations is influenced by the phenology, diversity, and relative preference of crops to the insects within a particular region. In North Carolina, the relative attractiveness of the flowering stages of crops to *H. zea* was: corn > tobacco > soybeans > cotton (Johnson et al. 1975). Regions with a diversity of crops extending through the season provide a continuum of reproductive sites extending beyond the attractive stage of any single crop. Such diversity results in more abundant populations (Fitt 1989). Crop diversity and succession in various regions of the U. S. are discussed by Bradley et al. (1986), Luttrell et al. (1986), and Rummel et al. (1986).

## POTENTIAL FOR ADULT MANIPULATION - ECOLOGICAL IMPLICATIONS

The ecological characteristics of *H. zea* populations provide both opportunities and constraints for manipulating adult populations with phytoattractants. In regions where reproduction in very early season is primarily associated with wild hosts, manipulation of the initial adult population would be more difficult. Such hosts are normally widely dispersed, poradic in occurrence, and, in many instances, plant populations at specific sites are small relative to the total land mass involved. Stadelbacher et al. (1986) estimated that, in the Mississippi Delta, 3.5% of the land mass served as early season habitat compared with about 79% devoted to farming. A spring survey of wild host plants in the Lower Rio Grande Valley (Raulston and Houghtaling 1986), revealed the following approximate plant populations: wild tobacco, *Nicotiana repanda* Willd, 3.5 plants/ha; bastardia, *Bastardia viscosa* L., 1.5 plants/ha; and amantillo, *Abutilon trisulcatum* (Jacq.) Urban, 1 plant/ha. This survey, which encompassed 17,000 ha, indicated low host plant populations relative to the total land mass.

The springtime abundance of flowering plants that are not used as reproductive hosts by *Heliothis/Helicoverpa* may also impose a constraint on manipulation of the initial adult population. Many of these flowering plants provide a nectar source for adults thereby eliminating the necessity for adults to concentrate feeding within specific areas. Nuttycombe (1930) observed *H. zea* feeding on 22 plant species near Charlottesville, VA. Our observations in the Lower Rio Grande Valley indicate that even in this semi-arid region, an abundance of wild flowers provide potential adult food sources in the spring. In addition to annual wild flowers, *H. zea* were also observed feeding on the blooms of native trees of the family Fabaceae, including mesquite, *Prosopis glandulosa* Torr.; huisache, *Acacia farnesiana* (L.) Willd; and retama, *Parkinsonia aculeata* L.

In areas where spring crop hosts are available, it may be possible to take advantage of their attractiveness to foster an initial concentration of adult populations. Applied phytoattractants which give false cues on the presence of an adult food source may then be used to further concentrate these moths in an area where their destruction may be effected. Such a system may be suitable for suppressing adult *H. zea* in areas such as the Lower Rio Grande Valley of south Texas and northeast Tamaulipas, Mexico. About 200,000 ha of spring corn, which serves as a reproductive host but provides no adult food source in the vegetative stage, are planted in this region. Raulston et al. (1990) studied the temporal relationships of the capture of *H. zea* adults in pheromone-baited traps, larval infestations and emergence of adults from corn in this region. Their data indicated that the initial larval infestation on whorl stage corn by *H. zea* corresponded temporally with similar infestations on wild host plants that were reported by Graham et al. (1972). However, because of the magnitude of the cropped host, Raulston et al. (1990) considered it to be the major source of subsequent *H. zea* generations in the region.

As stated previously, adult *H. zea* populations use a variety of sources for adult food (Nuttycombe 1930). Nocturnal observations of adults feeding on spring wildflowers in the Lower Rio Grande Valley in 1982 indicated that a night blooming weed *Gaura drummondii*

(Nutting 1930). Nocturnal observations of adults feeding on spring wildflowers in the Lower Rio Grande Valley in 1982 indicated that a night blooming weed *Gaura drummondii* (Spach)(Onagraceae) was very attractive to feeding moths, including at least 26 species in the family Noctuidae. Between Julian days 85 and 96, collections of *H. zea* adults were made in weedy and brushy areas along ditch banks, the peripheries of corn and cotton fields, and along the banks of the Rio Grande River to identify the plants being used as sources of food. Between 1900 and 0200 h, adults were collected from huisache, *Acacia farnesiana* (L.) Willd.; mesquite, *Prosopis glandulosa* Torr.; retama, *Parkinsonia aculeata* L.; dewberry, *Rubus* sp.; sunflower, *Helianthus* sp.; wild lettuce, *Lactuca* sp.; Trompillo, *Solanum elaeagnifolium* Cav.; mint, *Brazoria arenaria* Lundell; thistle, *Cirsium* sp.; *G. drummondii*, and various unidentified grasses. Of the 134 *H. zea* collected, 77% were feeding on *G. drummondii*. Similar collections were made between Julian days 132-135 (from 1900 to 2030 h) at College Station where *Gaura suffulta* Engelm., was observed along a roadside interspersed with blooming bluebonnet *Lupinus texensis* Hook or possibly *L. subcarnosus* Hook, Indian paint brush *Castilleja indivisa* Engelm., and evening primrose *Oenothera* sp. Of 127 *H. zea* adults collected, 78% were feeding on *G. suffulta*. This finding is significant because *G. suffulta* comprised <10% of the plant population. We observed *H. zea* adults approach *G. suffulta* from upwind, fly beyond, and subsequently orient to the plants indicating the possibility of volatile attractants.

In 1985, collections of *H. zea* adults were made near La Paloma, TX in a field of whorl stage corn and along an adjacent ditch bank which supported a dense population of *G. drummondii*, to determine if moths from the corn field were feeding on the *Gaura* blooms. Collections were made by at least two observers using headlamps and sweepnets in both corn and *Gaura*. Observation times ranged from 1830 to 2230 h and were divided into 30 min periods. In the early collections (1830-2030 h), *H. zea* adult collections per man hour in *G. drummondii* were significantly higher than in corn ( $F = 19.58$ ,  $df = 1,10$ ,  $P = 0.0013$ ) (Table 1). However, in the later time period (2030-2230 h) there was no significant difference

TABLE 1. Comparative Nocturnal Collections of *H. zea* from *Gaura drummondii* and Vegetative Corn. Collections Were Made Between March 27 and April 3, 1985.

Time of collection (hr)	Total collection man hours	Host	Collection per man hour <sup>a</sup>		
			Females	Males	Total
1830-2030	10.0	<i>Gaura</i>	19.9a	15.2a	35.1a
	7.5	Corn	3.5b	2.6b	6.1c
2030-2230	4.0	<i>Gaura</i>	12.0ab	8.5b	20.5b
	6.5	Corn	6.5b	6.5b	13.0bc

<sup>a</sup>Numbers within columns followed by the same letter are not significantly different ( $P > 0.05$ ) as determined by Duncan's multiple range test.

between *G. drummondii* and corn ( $F = 1.05$ ;  $df = 1,5$ ;  $P = 0.3522$ ) in the total collection per man hour. Although not significantly different, there was a trend for larger adult collections from *G. drummondii* during the early time period than from the later time period, while, adult collections in corn were larger in the late time period. These data suggest that during the major feeding period, moths left the corn field and concentrated in *Gaura*. Subsequently

these moths re-entered the corn to oviposit and mate.

This activity pattern was substantiated by determining the presence of *Gaura* pollen on the adults collected from corn (Table 2). Of 101 *H. zea* collected from corn, 42% had *Gaura* pollen adhering to their proboscis. That 45.6% of these moths were externally contaminated with other unidentified pollens suggested that they had fed on a variety of blooming plants. In addition, 91% of the moths collected from *Gaura* were contaminated with *Gaura* pollen and 32% were contaminated with other pollen taxa. The attractiveness of *G. drummondii* to feeding *H. zea* adults was further demonstrated by observing the number of moths feeding within a given area. Counts of *H. zea* adults were made in a 4 m<sup>2</sup> area comprising a dense

TABLE 2. Frequency of Pollen Contamination on Corn Earworm Adults Collected from Corn and *Gaura drummondii* in the Lower Rio Grande Valley. Collections Were Made Between March 27 and April 3, 1985.

Collection site	Number of adults collected	Percent with:		
		<i>Gaura</i> pollen	Other pollen	Total pollen
Corn	101	41.6	45.6	73.3
<i>Gaura</i>	362	91.0	32.3	94.5

patch of *G. drummondii* near La Paloma, TX in 1985. Counts were facilitated by using night vision goggles that were fitted with a supplemental infra-red light source. On each of the nights of 28 and 29 March and 1 April, two 30 min counts of *H. zea* adults were made between 1915 and 2200 h. An average of 43.5 *H. zea* moths entered the 4 m<sup>2</sup> arena per 30 min period with a maximum of 92 moths in one 30 minute period. The moths were observed feeding on the bloom nectaries and usually several different blooms were visited by each moth. The moths moved upwind through the arena and remained for 4 to 25 seconds at each bloom visited. These data indicated that the attraction by *G. drummondii* concentrated feeding *H. zea* moths to an average density of about 108,750 moths per ha.

Joyce (1982) indicated that in the Sudan Gezira, *Heliothis armigera* Hubner moved nightly from groundnut, where the moths had originated, to a flowering legume for feeding and then to cotton for reproduction. Our data indicate that *H. zea* goes from vegetative corn to feeding sites and then returns to corn where reproductive processes occur. This movement could offer an opportunity to manipulate *H. zea* moths with phytoattractants and facilitate suppression of the population with appropriate toxin-containing food sources. The attractiveness of *G. drummondii* as a feeding host suggests this plant contains volatiles that may be very promising for use in the development of phytoattractant systems. Lingren et al. (1990) subsequently demonstrated that the addition of thiodicarb to the blooms of *G. drummondii* killed 78% of *H. zea* adults exposed to the treated blooms. Indeed, these observations have formed the basis of a multidisciplinary effort to develop attracticide technology for suppressing *H. zea* populations (Lingren et al. unpublished data). Methods for obtaining volatile chemicals from plant sources and assessing their relative attractiveness are discussed by Shaver, et al. (this supplement). Isolation and identification of volatiles associated with *G. drummondii*, *G. suffulta*, and *G. longiflora*, has been accomplished (Teranishi et al. 1991, Kint et al. 1993). Shaver et al. 1994 also demonstrated the

attractiveness of *Gaura* spp. volatiles that were extracted from blooms and used as baits in Hartstack live traps (Hartstack et al. 1979). To be efficacious, adult suppression systems based on plant derived attractants will require an in-depth knowledge of the pest insect's ecology, population dynamics, and nocturnal behavior, to assure proper and timely placement of compounds to minimize competition of toxic baits with naturally occurring feeding sites in specific areas.

A second opportunity for manipulating adult *H. zea* occurs at emergence of the largest population associated with fruiting stage corn. This population emerges after corn is no longer attractive as a reproductive site and the adult population is required to disperse to new reproductive habitats. Raulston et al. (1992) estimated that in the Lower Rio Grande Valley, fruiting corn produced from 1.07-3.75 prepupae and pupae per m<sup>2</sup> and 67.1-94.6% were alive at the time the estimations were made. Raulston et al. (1992) also estimated that the 200,000 ha corn crop in the Lower Rio Grande Valley could produce enough *H. zea* to cause an economic infestation on 3.0-14.3 million ha of crops (Table 3). This estimation assumed that 10% of the pupae excavated from soil samples survived to reproductive maturity, that each female oviposited an average of 1,000 eggs, and that 25,000 eggs per ha would result in an economic infestation. Lingren et al. (1986) suggested that attractants associated with *Gaura* spp. could be used to develop a system for controlling adults emerging from mature corn. When *H. zea* peak emergence of *H. zea* from fruiting corn was occurring in the Lower Rio Grande Valley in June 1989, Wolf et al. (1990) used airborne radar to track a cloud of moths originating from the Lower Rio Grande Valley over 400 km to the north during a 7.7 h period. Meteorological soundings showed that the moths were being transported on nocturnal low level jets of wind. The advantages of suppressing an *H. zea* adult population,

TABLE 3. Estimated Regional Production of Live Corn Earworm Pupae From Fruiting Corn in the Lower Rio Grande Valley and Potential of Emerging Adults to Produce an Economic Infestation on Other Hosts.<sup>a</sup>

Year	Fields sampled	Live pupae/m <sup>2</sup> (SD) <sup>b</sup>	Estimated adults		Potential area infested by emerging adults (ha X 10 <sup>6</sup> ) <sup>c</sup>
			Total (X10 <sup>9</sup> ) <sup>c</sup>	Females (X10 <sup>8</sup> ) <sup>d</sup>	
1985	101	3.58a (2.86)	7.16	3.58	14.3
1986	120	2.57b (2.47)	5.14	2.57	10.3
1987	105	0.74c (1.0)	1.48	0.74	3.0
1988	90	2.76b (2.58)	5.52	2.76	11.0

<sup>a</sup>From Raulston et al. (1992).

<sup>b</sup>Numbers followed by the same letter are not significantly different ( $P>0.05$ ) by Duncan's multiple range test.

<sup>c</sup>Based on 100% emergence of all live pupae produced from 200,000 ha of corn in the Lower Rio Grande Valley.

<sup>d</sup>Assuming 10% survival to reproductive stage.

<sup>e</sup>Assuming each surviving female oviposits 1,000 eggs and an economic infestation level of 25,000 eggs per hectare.

of the magnitude originating in the Lower Rio Grande Valley at its source prior to migration, are evident.

One of the first activities of *H. zea* adults after emergence is feeding (Lingren et al. 1988). Indeed, we have observed feeding activity and movement of *H. zea* moths between corn fields located immediately south of the Rio Grande River to cotton fields immediately north of the river, as moths were emerging from the corn. As these moths moved across the river just after sundown, they fed on a number of wild flowers situated along the river bank including: *G. drummondii*; Texas virginsbower, *Clematis drummondii* T. & G.; common sunflower, *Helianthus annuus* L.; and on seed heads of buffelgrass, *Cenchrus ciliaris* L. In 1986, 77 female *H. zea* moths were collected from these wild flower feeding sites during the nights of Julian days 156 to 161. The frequency of mating of females collected from wild flowers was significantly lower than of those collected from cotton ( $F=60.93$ ;  $df=1,241$ ;  $P = 0.0001$ ) (Table 4). Only two females collected from wild flowers were mated. However, the subsequent mating status of 167 females collected from cotton changed significantly ( $F=17.26$ ;  $df=3,162$ ;  $P = 0.0001$ ), increasing from 25% mated on Julian day 156 to 76.6% on Julian day 161. Thus, moths crossing the river were newly emerged and searching for attractive feeding and reproduction sites. The wild flowers along the river bank were used for feeding because they were the first attractive sites encountered by the dispersing moths after they left the corn. Upon arrival in the cotton fields just north of the river, this population became resident and began to mate and reproduce.

TABLE 4. Mating Status of *H. zea* Collected From Uncultivated Plants Used as Feeding Sites and From Cotton During the Emergence Cycle From Fruiting Corn in the Lower Rio Grande Valley During 1986.

Day of year	Collection site	Number collected		Spermatophores per female <sup>a</sup>
		males	females	
156	wild flowers	3	12	0.00c
	cotton	25	28	0.32bc
157	wild flowers	19	30	0.00c
	cotton	32	49	0.69b
158	wild flowers	11	18	0.06c
	cotton	13	17	0.47bc
161	wild flowers	17	17	0.06c
	cotton	44	72	1.58a

<sup>a</sup>Numbers followed by the same letter are not significantly different ( $P > 0.05$ ) as determined by Duncan's multiple range test.

Data collected in cotton fields near Narrabri, New South Wales, Australia (J. R. Raulston, G. P. Fitt and R. A. Farrow, unpublished data), in 1987 also indicated the propensity of virgin *H. armigera* to disperse. During the course of an investigation of the nocturnal activity of *H. armigera*, two 50 ha cotton fields in which observations were being made received two pesticide applications. Pre- and post-application collections of adults allowed an evaluation of the effect of these sprays on the mating status of the population. An initial spray of alphamethrin was made at 2200 h on the night of Julian day 27; examination of adults collected before the spray indicated 77.8% of the resident *H. armigera* females were mated

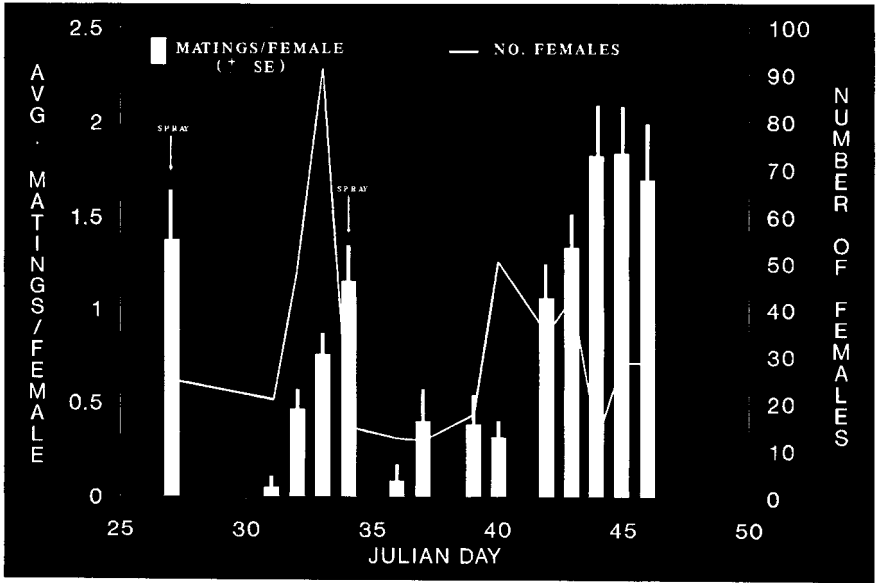


FIG. 1. Effect of pesticide application on the mating status of *H. armigera* females collected from cotton fields near Narrabri, New South Wales, Australia. 1987.

day 31, 9 of the 20 females collected were mated and the population averaged 0.05 matings per female (Fig. 1). The percentage of females mated and the number of matings per female continued to increase through Julian day 34 when a second spray of endosulfan + chlorpyrifos was applied at 2300 h. Before this spray, the adult population was 74.1% mated with an average of 1.2 matings per female. On the night of Julian day 36, only 7.1% of females were mated with an average of 0.08 matings per female. Changes occurring after the second spray followed a pattern similar to that observed after the first spray, with percentage mated and the average number of matings per female increasing until the cessation of the experiment on Julian day 46. At this time, 82.1% of females were mated with an average of 1.7 matings per female.

The propensity of newly emerged *Helicoverpa* spp. moths to move and feed suggests they could be manipulated and subsequently suppressed with appropriate attracticide systems before reproduction. To test this concept, Lingren et al. (1990) banded corn stubble with a mixture of sorghum molasses and thiodicarb in a field where adult *H. zea* were emerging. Of 22 emerging moths placed at the base of treated stalks, 100% fed and died. When thiodicarb in water was banded on the stalk only 27% mortality occurred, indicating the feeding stimulant (sorghum molasses) increased the efficacy. Use of a system based on this technology might reduce a possible migrant population as well as that portion of the population destined to remain on local crops.

#### SUMMARY

Techniques to manipulate and control adult populations of lepidoptera with phytoattractants are now being developed. The utility of such technology has not been tested



in depth. However such techniques have been used to suppress field populations of several tephritid fruit flies (*Dacus dorsalis* Hendel, Steiner et al. 1965; *D. cucurbitae* Coquillett, Cunningham and Steiner 1972; and *D. tryoni*, Bateman et al. 1973), the Japanese beetle, *Popillia japonica* Newman (Hamilton et al. 1971), and a corn rootworm, *Diabrotica virgifera virgifera* LeConte (Metcalf et al. 1987, Lance and Sutter 1992). We have not attempted to address the impact of adult population suppression on the subsequent ability of that population to increase. Considering their mobility, polyphagous nature, and high intrinsic rate of increase, it is unlikely that reduction of *H. zea* populations by adult manipulation would result in the elimination of reproduction. The impact of survivors must be considered. It is conceivable, however, that many situations exist in our present-day agroecosystems where mobile noctuid adults may be manipulated to effect an overall reduction in their populations. Success of such technology would depend on a thorough evaluation of insect population dynamics and ecology within specific areas or regions. Factors to be addressed include seasonal population origins, host cropping sequences, and availability of native hosts. As Metcalf (1987) stated, "The technology of use of kairomones in integrated pest management of insect pests appears to have virtually limitless possibilities and can provide the impetus for development of new and novel methods of insect pest suppression."

#### LITERATURE CITED

- Bateman, M.A., S. Insuza, and F. Arretz. 1973. The eradication of the Queensland fruitfly from Easter Island. *FAO Plant Prot. Bull.* 21: 111.
- Bradley, Jr., J. R., C. A. Herzog, S. H. Roach, R. E. Stinner, and L. I. Terry. 1986. Cultural control in southeastern U.S. cropping systems, pp. 22-27. *In* S. J. Johnson, E. G. King, and J. R. Bradley, Jr. [eds.], *Theory and Tactics of Heliothis Population Management: I-Cultural and Biological Control*. South. Coop. Ser. Bull. 316. 161 pp.
- Cunningham, R. T., and L. F. Steiner. 1972. Field trial of cue-lure and + naled on saturated fiberboard blocks for control of the melon fly by the male-annihilation technique. *J. Econ. Entomol.* 65: 505-507.
- Ditman, L. P. 1937. Observations on poison baits for corn earworm control. *J. Econ. Entomol.* 30: 116-118.
- Fitt, G. P. 1989. The ecology of *Heliothis* species in relation to agroecosystems. *Annu. Rev. Entomol.* 34: 17-52.
- Glover, T. 1855. Insects injurious and beneficial to vegetation. *Rept. of the Comm. of Patents for the Year 1854*.
- Glover, T. 1865. Report of the Entomologist. *Rept. of the Comm. of Agric. for the Year 1864*.
- Graham, H. M., and O. T. Robertson. 1970. Host plants of *Heliothis virescens* and *H. zea* (Lepidoptera: Noctuidae) in the Lower Rio Grande Valley, Texas. *Ann. Entomol. Soc. Amer.* 63: 1261-1265.
- Graham, H. M., N. S. Hernandez, Jr., and J. R. Llanes. 1972. The role of host plants in the dynamics of populations of *Heliothis* spp. *Environ. Entomol.* 1: 424-430.
- Hamilton, D. W., P. H. Schwartz, B. G. Townsend, and C. W. Jester. 1971. Traps reduce an isolated infestation of Japanese beetle. *J. Econ. Entomol.* 64: 150-153.
- Hartstack, A. W., J. A. Witz, and D. Buck. 1979. Moth taps for the tobacco budworm. *J. Econ. Entomol.* 72: 519-522.

- Hedin, P. A., F. G. Maxwell, and J. N. Jenkins. 1974. Insect plant attractants, feeding stimulants, repellents, deterrents and other related factors affecting insect behavior, pp. 494-527. *In* F. G. Maxwell and F. A. Harris [eds.], Proc., Summer Institute on Biological Control of Plant Insects and Diseases. University Press of Mississippi, Jackson, MS. 647 pp.
- Johnson, N. W., R. E. Stinner, and R. L. Rabb. 1975. Ovipositional response of *Heliothis zea* (Boddie) to its major hosts in North Carolina. *Environ. Entomol.* 4: 291-297.
- Joyce, R. J. V. 1982. A critical review of the role of chemical pesticides in *Heliothis* management, pp. 173-188. *In* W. Reed and V. Kumble [eds.], Proc., International Workshop on *Heliothis* Management, 15-20 Nov. 1981, ICRISAT Center, Patancheru, A.P., India.
- Kint, S., R. Teranishi, P. D. Lingren, T. N. Shaver, and J. R. Raulston. 1993. Chemical composition of *Gaura suffulta* and *Gaura longiflora* flower volatiles. *J. Ess. Oil Res.* 5: 201-203.
- Lance, D. R., and G. R. Sutter. 1992. Field tests of a semiochemical-based toxic bait for suppression of corn rootworm beetles (Coleoptera: Chrysomelidae). *J. Econ. Entomol.* 85: 967-973.
- Lingren, P. D., and J. R. Raulston. 1986. Emergence behavior and generation dynamics of corn earworm. Proc. 5th Annual Hort. Industries Show, Tulsa, OK., 1986: 60-65.
- Lingren, P. D., W. B. Warner, J. R. Raulston, M. Kehat, T. J. Henneberry, S. D. Pair, A. Zvirgzdins, and J. M. Gillespie. 1988. Observations on the emergence of adults from natural populations of corn earworm, *Heliothis zea* (Boddie) (Lepidoptera: Noctuidae). *Environ. Entomol.* 17: 254-258.
- Lingren, P. D., J. R. Raulston, T. N. Shaver, and E. V. Wann. 1990. Mortality of newly emerged adult corn earworms following treatment with a feeding stimulant bait. Proc. 9th Annu. Hort. Industries Show, Tulsa, OK., 1990: 126-132.
- Lincoln, C., G. Dean, J. R. Phillips, E. J. Matthews, and G. S. Nelson. 1966. Molasses-insecticide sprays for control of bollworm. *Ark. Farm Res.* 15: 4.
- Luttrell, R. G., J. R. Phillips, and T. R. Phrimmer. 1986. Cultural control in mid-South U.S. cropping systems, pp. 28-37. *In* S. J. Johnson, E. G. King, and J. R. Bradley, Jr. [eds.], Theory and Tactics of *Heliothis* Population Management: I-Cultural and Biological Control. South. Coop. Ser. Bull. 316. 161 pp.
- Malley, F. W. 1983. Report on the cotton bollworm. USDA, Div. Entomol., Bull. No. 24, pp. 38-39.
- Metcalf, R. L. 1987. Plant volatiles as insect attractants. *CRC Critical Reviews in Plant Science* 5: 251-301.
- Metcalf, R. L., J. E. Ferguson, R. Lampman and J. R. Anderson. 1987. Dry cucurbitacin-containing baits for controlling diabroticite beetles (Coleoptera: Chrysomelidae). *J. Econ. Entomol.* 80:870-875.
- Neunzig, H. H. 1963. Wild host plants of the corn earworm and the tobacco budworm in eastern North Carolina. *J. Econ. Entomol.* 56: 135-139.
- Nuttycombe, J. W. 1930. Oviposition of the corn earworm moth in relation to nectar flow of some flowering plants. *J. Econ. Entomol.* 23: 725-729.
- Quaintance, A. L., and C. T. Brues. 1905. The cotton bollworm. USDA, Bur. Entomol. Bull. No. 50. 155 pp.
- Rabb, R. L. 1979. Regional research on insect movement: Initial considerations, pp. 2-12. *In* R. L. Rabb and G. G. Kennedy [eds.], Movement of Highly Mobile Insects: Concepts and Methodology in Research, University Graphics, North Carolina State University, Raleigh, NC. 465 pp.

- Raulston, J. R., and J. E. Houghtaling. 1986. Circumstantial ecological evidence for *Heliothis virescens* migration into the Lower Rio Grande Valley of Texas and northeastern Mexico, pp. 34-47. In A. N. Sparks [ed.], Long Range Migration of Moths of Agronomic Importance to the United States and Canada: Specific examples of Occurrence and Synoptic Weather Patterns Conducive to Migration, USDA ARS-43. 104 pp.
- Raulston, J. R., K. R. Summy, J. E. Loera, S. D. Pair, and A. N. Sparks. 1990. Larval population dynamics of *Heliothis zea* Boddie (Lepidoptera: Noctuidae) on corn in the Lower Rio Grande Valley. *Environ. Entomol.* 19: 274-280.
- Raulston, J. R., S. D. Pair, J. Loera, A. N. Sparks, W. W. Wolf, J. K. Westbrook, G. P. Fitt, and C. E. Rogers. 1992. *Helicoverpa zea* (Lepidoptera: Noctuidae) pupa production in fruiting corn in northeast Mexico and south Texas. *Environ. Entomol.* 21: 1393-1397.
- Rummel, D. R., J. F. Leser, J. E. Slosser, J. G. Puterka, C. W. Neeb, J. K. Walker, J. H. Benedict, M. D. Heilman, L. N. Namkin, J. W. Norman, and J. H. Young. 1986. Cultural control of *Heliothis* spp. in southwestern U.S. cropping systems, pp. 38-51. In S. J. Johnson, E. G. King, and J. R. Bradley, Jr. [eds.], Theory and Tactics of *Heliothis* Population Management: I-Cultural and Biological Control. South. Coop. Ser. Bull. 316. 161 pp.
- Stadelbacher, E. A., H. M. Graham, V. E. Harris, J. D. Lopez, J. R. Phillips, and S. H. Roach. 1986. *Heliothis* populations and wild host plants in the southern U.S., pp. 54-74. In S. J. Johnson, E. G. King, and J. R. Bradley, Jr. [eds.], Theory and Tactics of *Heliothis* Population Management: I-Cultural and Biological Control. South. Coop. Ser. Bull. 316. 161 pp.
- Steiner, L. F., W. C. Mitchell, E. J. Harris, T. T. Kozuma, and M. S. Jujimoto. 1965. Oriental fruitfly eradication by male annihilation. *J. Econ. Entomol.* 58: 961.
- Stinner, R. E., J. Ragneire, and K. Wilson. 1982. Differential effects of agroecosystems structure on dynamics of three soybean herbivores. *Environ. Entomol.* 11: 538-543.
- Teranishi, R., R. G. Buttery, S. Kint, G. Takeoka, P. D. Lingren, J. R. Raulston, and T. N. Shaver. 1991. Chemical composition of *Gaura drummondii* flower volatiles. *J. Ess. Oil Res.* 3: 287-288.
- Wolf, W. W., J. K. Westbrook, J. R. Raulston, S. D. Pair, and S. E. Hobbs. 1990. Recent airborne radar observations of migrant pests in the United States. pp. 619-630. In R. C. Rainey, K. A. Browning, R. A. Cheke, and J. J. Haggis (eds.), Migrant Pests: Progress, Problems and Potentialities. *Phil. Trans. R. Soc. Lond. B* 328.