TEMPORAL OCCURRENCE OF *HELICOVERPA ZEA*[1] (BODDIE), POPULATIONS ON CORN IN THE LOWER RIO GRANDE VALLEY, UVALDE AND LUBBOCK, TEXAS

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ABSTRACT

Corn earworm, *Helicoverpa zea* (Boddie), pheromone trap capture, larval infestation and adult emergence was monitored in corn in the Lower Rio Grande Valley (26.2° N, 98.0° W), Uvalde (29,2° N, 99.7° W), and Lubbock (33.5° N, 101.8° W), Texas. On a regional scale, larval infestation of fruiting corn and adult emergence from pupae excavated from maturing corn fields provided discrete population events that were well separated by location. In most instances trap capture of adults appears, on a local scale, to be related to these two events. However, in early season, the variability observed in trap capture and larval infestations on vegetative corn within regions provide difficulty in temporally defining the occurrence of meaningful events related to these variables across regions. When ambient air temperatures and wind velocity occurring during trap capture peaks were compared to those occurring two days prior and two days after after the peaks only minor correlations were observed. The implications are that trap capture values did not abruptly change with either significantly warmer or cooler temperatures or with increased or decreased zonal or meridional wind speed. We conclude that the atmospheric factors used as independent predictor variables were not correlated with the response of corn earworm males to pheromone traps, or with the long-distance atmospheric transport of populations into the trapping area. Our data further show that simulated nocturnal trajectories, calculated during peak adult emergence periods within regions, provide a mechanism for determining the atmospheric systems available to transport moths from one region to another.

INTRODUCTION

The genera *Heliothis* and *Helicoverpa* contain some of the

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most serious pests of row crop agriculture throughout the world. Their status as pests is attributed in part to their mobility (Farrow and Daly 1987) and their highly polyphagous nature. They are well adapted to exploitation of unstable habitats exemplified by most row crop agroecosystems, and can rapidly deploy their populations between fields, different crops and naturally occurring host plants. Knipling (1979) stated that a knowledge of migratory habits and the impact of migration on population development was a major criterion for development of area-wide insect management systems.

Farrow and Daly (1987) developed a classification scheme to describe the movement of *Heliothis/Helicoverpa* adults which included short-range (< 1km), long-range (1-10 km) and migratory (10-500 km) movement. Although this classification may be somewhat arbitrary, it provides a conceptual framework for discussion of movement. Within this framework, short-range movement involves movement instrumental to survival of the individual (feeding and seeking of refugia) as well as reproduction (searching for host plants, oviposition and mate seeking). This movement is closely associated with the crop canopy, with the adults oriented up- or cross-wind in response to chemical stimuli emitted by host plants or sexually receptive mates. During the fruiting stage, many row crops such as corn and cotton provide food, shelter and reproductive sites, however, movement between fields and crops result in a constant redistribution of adults on a local scale (Haggis 1982, Joyce 1982, Stinner et al. 1982).

Long range movement as defined by Farrow and Daly (1987) involves searching for more attractive host sites. In many instances, long range movement can still be considered appetitive since it may involve the seeking of feeding sources, refugia and mates. This type of movement also occurs when attractive hosts mature and the adults begin to colonize other hosts hosts that may be considered less attractive but are still in the fruiting stage (Quaintance and Brues 1905, Garman and Jewett 1914, Pepper 1943, Stinner et al. 1982, Raulston et al. 1986a, and Raulston et al. 1986b). Orientation and displacement associated with long range-movement is usually downwind and occurs within the first few tens of meters above the crop canopy.

Migratory movement can result in displacement of adults over distances of hundreds of kilometers and provides another mechanism for exploitation of ephemeral habitats. Migratory movement of *Heliothis/Helicoverpa* appears to occur in response to decaying habitat and may thus be facultative (Hackett and Gatehouse 1982). Migratory movement typically begins at dusk (Lingren and Wolf 1982, Drake 1984, 1985, Wolf et al. 1986), and the adults rapidly ascend to altitudes of up to 1000 meters. These adults often form layers near the levels of maximum wind velocity associated with nocturnal low level jets, for effecting transport (Drake 1985, Wolf et al. 1986). The wind velocity in these nocturnal low level jets frequently exceeds 50-60 km per hr and can result in transport of moths over 300 km within 5 hr. Drake and Farrow (1988) review the atmospheric structures that provide transport mechanisms facilitating migratory movement.

Among the requisites for determining the impact of migrating populations are the temporal and spatial definition of insect populations developing in both source (donor) and recipient areas. Through careful assessment of the development of populations on regional scales, occurrences of population phenomena such as oviposition and trap capture peaks asynchronous with local population development, may be detected.

Changes in local and regional (synoptic) atmospheric conditions, such as air temperature, precipitation, and wind speed and direction, are primary factors that govern when and where population distributions through long distance migration occur. Abrupt increases in trap capture are often associated with synoptic-scale meteorological events such as frontal passages that present mechanisms for strong transport, convergence and deposition of airborne insects (Farrow and Daly 1987, Raulston et al. 1986b). Thus, population dynamics data, coupled with meteorological and entomological radar data, can provide insight for determining the impact of migration on developing populations of *Heliothis/Helicoverpa*.

We report here meteorological observations and data on the population dynamics of the corn earworm, *Helicoverpa zea* (Boddie), at three locations extending from northeastern Tamaulipas, Mexico to Lubbock, Texas. This study was designed to determine the chronology of developing corn earworm populations within different corn growing regions of Texas. These data will aid in determining the interregional migration of adult moths.

MATERIALS AND METHODS

Monitoring adults. Cone type pheromone traps (Hartstack et al. 1979) constructed of 8X8 mesh hardware cloth were used to monitor the presence of adult male corn earworms. Traps were baited biweekly with Hercon dispensers (Hercon Division, Health-Chemical Corporation, South Plainfield, N.J.) containing 40 mg of zealure. In the Lower Rio Grande Valley,(LRGV) (26.2° N, 98.0° W), 12 pheromone traps, installed in 4 lines with 3 traps/line were observed throughout the year from 1988-1990. Traps within lines were separated by about 1.6 km and lines were separated by 8-16 km. In 1990, six pheromone traps were monitored at Uvalde (29.2° N, 99.7° W), between days 110 and 204 and at Lubbock (33.5° N, 101.8° W), between days 128-235. The traps were located near corn fields that were to be observed for corn earwrom larval infestation and were a minimum of 5 km apart. At all locations, trap capture data were recorded 5 days/week.

Monitoring Larval Infestations. From 1988-1990, the occurrence of corn earworm larvae was monitored in 8-10 commercial corn fields located near Rio Bravo (situated in the Lower Rio Grande Valley of northeast Tamaulipas, Mexico). Fields were sampled between days 81-154, 79-156, and 74-158 in 1988, 1989, and 1990, respectively. Fields were normally sampled twice a week. In each field, 50 randomly selected plants were examined for larval infestation on each sampling day. Plants were selected by pacing five-ten steps from the last sample, crossing two rows and choosing the plant nearest the observers foot at the last pace. In whorl stage corn, the whorl leaves were removed from the plant, unfurled and checked for larvae. In silking corn, only the primary ear was examined for infestation. All observed larvae were classified according to species and size (very small < 5 mm, small 5-10 mm, medium 10-20 mm, and large > 20 mm). The infestation records were combined and averaged over weekly periods. For this report, infestations by small larvae include eggs, very small and small larvae combined.

Larval infestation was monitored in six corn fields at Uvalde and Lubbock in 1990 following the previously described procedures. Fields were sampled between days 113-186 and 134-214 at Uvalde and Lubbock, respectively.

Emergence Monitoring. From 1988-1990, corn earworm pupae were excavated from two, 1 m^2 samples in each of 90-100 commercial corn fields in the Rio Bravo area following the procedures of Raulston et al. (1992). Pupae were excavated after mature larvae had exited the corn ear and entered the soil to pupate. The pupae were placed in small emergence cages, reburied to a depth of about 5 cm in a commercial corn field and monitored daily for emergence. The emergence cages consisted of a 6.5 cm length of polyethylene tubing (9 mm inside diameter) inserted into the center of a 5 cm diameter polyethylene cup lid. A 5 cm diameter cylinder (5 cm high) made of 18 mesh aluminum screen. This cylinder, when covered with another 5 cm diameter cup lid, served as the above-ground portion of the cage into which the moth could emerge. A pupa was placed in the lower end of the polyethylene tube, which was then plugged with cotton. Subsequently the tube was inserted into the soil and functioned as the pupal chamber. Also, in 1989 and 1990, pupae were excavated from 40 corn fields near Uvalde, Texas and in 1990 from 6 corn fields near Lubbock, Texas. However, six 1 m^2 samples were excavated in each field at Lubbock. Emergence monitoring procedures were as previously described.

Statistical Analyses of Population Dynamics Data. Significant fluctuations in corn earworm larval populations on corn were determined using the method described by Raulston et al. (1992). Briefly, the larval populations were assumed to be normally distributed and each observed plant was tallied as either infested or not infested. Observed frequencies were averaged across fields for each week to provide an average frequency of infestation. Confidence intervals were calculated using the formula:

$$\bar{x} \pm 1.96 \sqrt{\frac{\bar{x}(1 - \bar{x})}{n}}$$

where n = the total number of plants observed per week. Infestation frequencies were considered significantly different ($P < 0.05$) if confidence intervals did not overlap.

Cumulative percent emergence of corn earworm pupae excavated from each region were calculated and compared statistically using Kolmogorov's statistic for finite sample size (Birnbaum 1952).

Meteorological Observations. Nocturnal atmospheric trajectories were simulated for the periods of peak emergence of corn earworm from pupae excavated from fields near Rio Bravo (1988-1990), Uvalde (1989-1990) and Lubbock (1990) using the methods of Westbrook et al. (1990). The trajectories were based on synoptic weather data obtained from the National Weather Service. Each trajectory was calculated for an altitude of 500 m above ground level (AGL) for successive flights of one night duration assuming 12 hr of flight each night. This altitude was chosen since Wolf et al. (1990) reported predominant insect flight from 200 m to 700 m altitude during a period of peak corn earworm emergence in, and migration from, the LRGV in 1989. An additional speed of 5 m/sec was added to the wind speed to simulate the flight speed of the moths. Although no other insect behavioral components (crabbing or changing of flight altitude) were included, the trajectories indicate the general direction and distance of transport.

Atmospheric data records (minimum surface air temperature, vertical profiles of air temperature, wind speed and wind direction) were also obtained from the National Weather Service to determine if these parameters influenced trap capture at the three test locations. Singular and successive dates of peak capture were manually determined by inspecting daily trap capture data in the LRGV, (1988-1990), Uvalde and Lubbock, Texas (1990). Six dates of peak capture (days 68, 84, 98, 104, 111, and 117) were identified at LRGV in 1988, ten dates (days 31, 47-52, 61, 80, 94, 109, 143, 178, 188, and 192) in 1989, and ten dates (days 47, 58, 65, 75, 93-95, 100-109, 144-149, 164, 179, and 195-197) in 1990. In 1990, three dates of peak capture (days 150, 158, and 165) were identified at Uvalde, and seven dates (days 144-152, 171, 193, 207, 215, 221, and 229) at Lubbock.

The minimum surface air temperature data were valid for the 12 hr prior to the observation time (typically about 0800 local time). Average surface air temperatures were obtained by averaging the values measured at 0600 and 1800 h. The vertical profiles were also measured at 0600 and 1800 hours daily. The horizontal wind speed was separated into two components, zonal and meridional, to measure the east-west and north-south contributions, respectively. Zonal wind speed is positive from a westerly direction, and negative from an easterly direction. Meridional wind speed is positive from a southerly direction, and negative from a northerly direction. Vertical profiles of the zonal and meridional wind velocity components at 500 m AGL were linearly interpolated from the 0600 and 1800 h profiles. Averages of the wind velocity were obtained from the 0600 and 1800 h profiles for the zonal and meridional wind velocity components.

Since corn earworm populations undergo generational cycles of about 30 days, the correlation and linear regression of peak capture with atmospheric variables could not be directly established meaningfully. Instead, anomalous values of the dependent variable (average daily trap capture) and five independent variables (minimum surface air temperature, average surface air temperature, and average air temperature at 500 m AGL, average zonal wind speed at 500 m AGL, and average meridional wind speed at 500 m AGL) were determined. Here an anomalous value is defined as the value of the variable measured on the date(s) of peak capture minus the average of the four values measured two days before and after the date(s) of peak capture. The anomalous value represents the departure of the measure of the variable from this average and may be positive or negative.

The mean, standard error and t-score ($P = 0.05$) of the anomalous values were computed for the dependent variable and five independent variables. The t-score was used to test the significance of the null hypotheses that the mean anomalous values equaled zero, and therefore the independent variables had no significant effect on the occurrence of peak trap captures.

RESULTS

Adult Monitoring. In 1988, an initial small capture peak of corn earworm males occurred in the LRGV between days 65-71 with the peak (58 males per trap) occurring on day 68 (Fig. 1). Trap capture began to increase on day 82 and a second capture peak occurred on day 111. The third peak capture period began on day

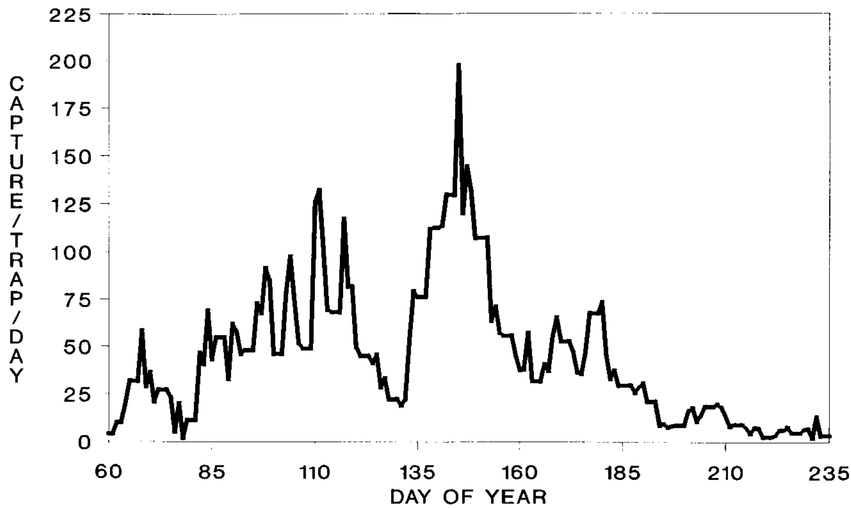

FIG. 1 Average daily trap capture of corn earworm males in the Lower Rio Grande Valley, 1988.

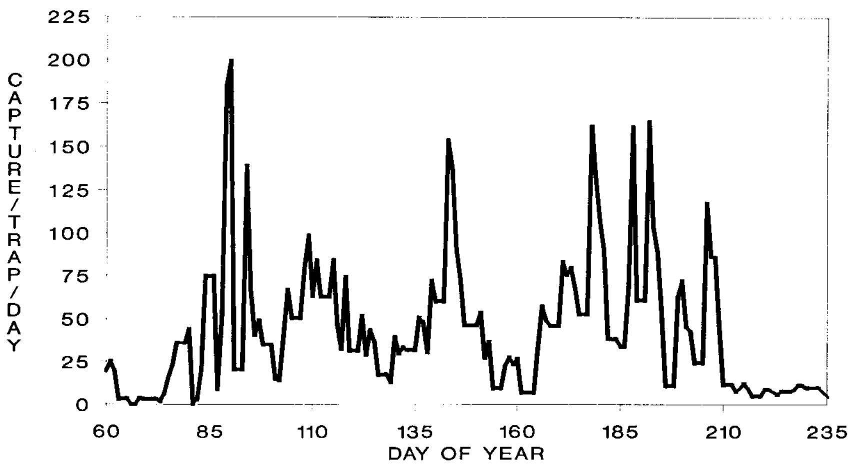

FIG. 2. Average daily trap capture of corn earworm males in the Lower Rio Grande Valley, 1989.

133 and peaked at 197 males per trap on day 145. The regional corn crop was silking during the week ending on day 135 (Table 1). A fourth but smaller peak capture period occurred between days 168-180 with the peak (73 males per trap) occurring on day 180. This capture peak occurred during the peak adult emergence from fruiting corn (Table 2).

The initial peak trap capture period in 1989 at LRGV occurred between days 84-95 with the peak (199 males per trap) occurring on day 90 (Fig. 2). A second capture peak of 98 males per trap occurred on day 109. The third peak capture period occurred between days 136-146 with the peak (153 males per trap) occurring on day 143. Again this peak was associated with silking corn (Table 1). An extended fourth peak capture period that encompassed adult emergence from fruiting corn occurred between days 166-193. The capture peak associated with emergence from fruiting corn in 1989 was much larger than that observed in 1988.

The trap capture profile in the LRGV in 1990 was similar to that observed in 1989 (Fig. 3). However, the third capture peak (days 144-149) occurred during adult emergence from fruiting corn (Table 2), and no capture peak was observed during the silking period. Interestingly, capture peaks at LRGV in 1990 were much lower than observed in 1988 or 1989.

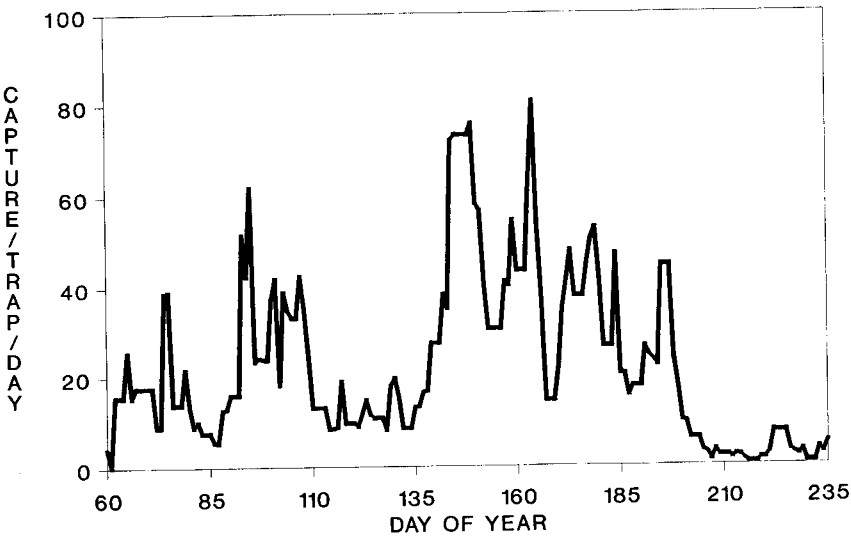

FIG. 3. Average daily trap capture of corn earworm males in the Lower Rio Grande Valley, 1990.

In 1990 at Uvalde, high captures of corn earworm were observed at the time of trap installation (Fig. 4). The first peak capture period occurred between days 114-130 with the peak (208 males per trap) occurring on day 121. Low trap captures were observed at LRGV during this time (Fig. 3). The second capture peak at Uvalde occurred between days 146-159 with the peak capture occurring on day 149. Corn at Uvalde was silking during the week ending on day 153 (Table 1), and adult emergence was occurring from fruiting corn at (Table 2). This capture peak may have been augmented by immigration from LRGV. The third peak capture period extended for 23 days (days 170-193) with the peak (403 males per trap) occurring on days 185-186. This capture peak occurred during local emergence from fruiting corn (Table 2).

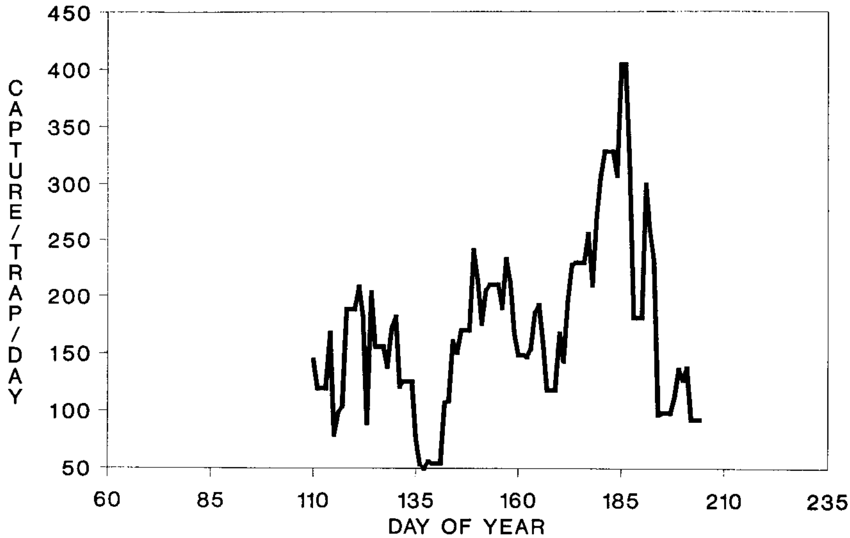

FIG. 4. Average daily trap capture of corn earworm males at Uvalde, 1990.

A small capture peak occurred in 1990 at Lubbock between days 142-152 with the peak (85 males per trap) occurring on day 145 (Fig. 5). This peak was in synchrony with the adult emergence occurring at LRGV (Table 2) as well as the second trap peak occurring at Uvalde (Fig. 4). A second peak (243 males per trap) occurred at Lubbock on day 171. Corn was silking in the area during the week ending day 180 (Table 1). The largest peak (513 males per trap) at Lubbock occurred on day 193. Over 90% of the adult emergence had occurred at Uvalde by this time (Table 2), however, no emergence from the local corn crop occurred before day 225.

Monitoring Larval Infestations. Corn infestation by small corn earworm larvae at LRGV, Uvalde and Lubbock are presented in Table 1. In 1988, the largest infestation on vegetative corn at LRGV (10-10.6%) occurred during the two week period ending day 107, however, there was no significant difference between the weekly infestations throughout the remainder of the vegetative growth stage. This infestation occurred during the extended second peak trap capture period (Fig. 1). Larval infestation on fruiting corn was initiated during the week ending day 135 and

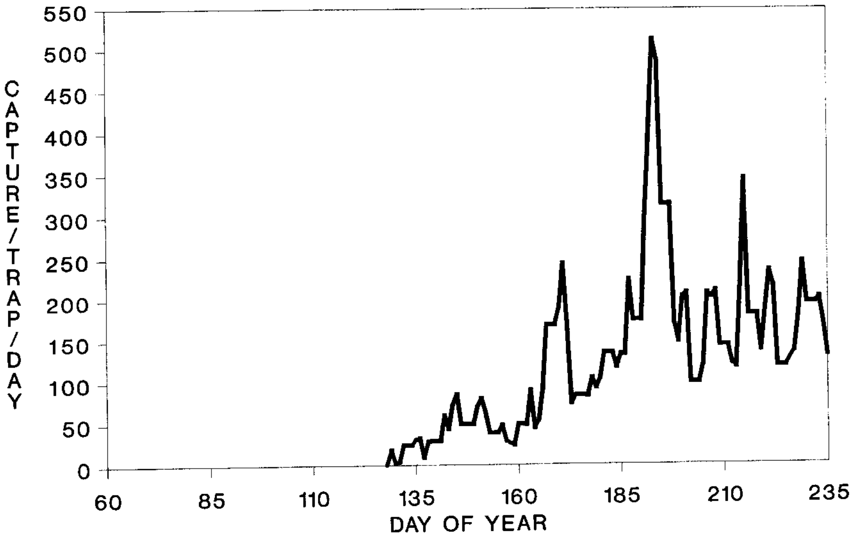

FIG. 5. Average daily trap capture of corn earworm males at Lubbock, 1990.

increased through the week ending day 142 (Table 1). The second trap capture peak was occurring during this period (Fig. 1).

Small corn earworm larval infestation at LRGV in 1989 was similar to that observed in 1988 with the peak on vegetative corn occurring during the week ending day 98. Peak infestation on fruiting corn occurred during the two week period ending day 147.

The corn crop at LRGV in 1990 was earlier than in 1988 or 1989. As a result, the small corn earworm larval peak infestation on vegetative corn was observed during the initial week of observation ending on day 76. Further, the infestation on fruiting corn began about 21 days earlier than the previous two years. However, the small larval infestation on fruiting corn was protracted over a 35 day period.

Infestation on vegetative corn at Uvalde in 1990 was significantly higher than observed at LRGV (Table 1). The highest infestation (16%) occurred during the week ending day 125, however, this infestation was not statistically different from the infestation observed throughout the vegetative growth period. The infestation on silking corn peaked during the two week period ending day 160. Over 80% of the adult emergence from fruiting corn had occurred at LRGV by this time (Table 2).

Corn earworm infestation on corn at Lubbock in 1990 was initially observed during the week ending day 146 (Table 1). This infestation subsequently increased each week throughout the remainder of the vegetative growth period and peaked during the week ending day 174. The infestation on vegetative corn at Lubbock was synchronized with adult emergence at LRGV (Table 2). Silking occurred at Lubbock during week 26 with a concomitant

TABLE 1. Infestation of Corn by Small Corn Earworm Larvae at LRGV, Uvalde and Lubbock Texas[a].

Week	Percent of plants infested[b]				
	LRGV			Uvalde	Lubbock
	1988 (8)[c]	1989 (10)	1990 (10)	1990 (6)	1990 (6)
11	-	-	10.3(7.3-13.2)	-	-
12	-	1.4(0.7-2.1)	9.7(7.7-11.6)	-	-
13	3.1(1.9-4.3)	8.0(6.3-9.7)	6.5(5.0-8.0)	-	-
14	10.0(7.9-12.1)	15.5(13.3-17.7)	4.7(3.4 6.0)	-	-
15	10.6(8.5-12.8)	8.3(6.3-10.2)	5.6(4.2-7.0)	-	-
16	8.3(6.3-10.2)	9.5(7.7-11.3)	4.8(3.5-6.1)	-	-
17	7.3(5.5-9.1)	8.8(7.0-10.6)	15.6(13.4-17.9)[d]	8.7(5.3-12.1)	-
18	7.6(5.8-9.5)	11.5(9.5-13.4)	23.2(19.5-26.9)	16.0(13.1-18.9)	-
19	5.3(3.8-6.9)	6.0(4.5-7.5)	23.1(20.0-26.3)	12.0(9.4-14.6)	-
20	21.0(18.0-24.0)[d]	33.2(30.2-36.2)[d]	25.9(23.2-28.6)	10.0(6.9-13.4)	0.0(0-0)
21	36.6(33.3-40.0)	30.2(27.4-33.1)	22.9(20.3-25.5)	12.5(9.8-15.3)	2.6(1.2-4.0)
22	23.3(20.9-25.6)	6.4(4.9-7.9)	7.8(5.5-10.2)	44.7(40.6-48.9)[d]	4.0(1.6-6.4)
23	4.8(3.3-6.2)	1.4(0.4-2.4)	0.5(0.1-0.9)	53.5(49.3-57.7)	6.4(4.7-8.0)
24	-	-	-	12.0(9.3-14.7)	7.2(4.0-10.4)
25	-	-	-	3.1(1.8-4.6)	11.8(8.6-14.9)
26	-	-	-	0.0(0-0)	23.0(19.3-26.7)[d]
27	-	-	-	-	38.0(31.3-44.7)
28	-	-	-	-	72.4(66.9-77.9)
29	-	-	-	-	-
30	-	-	-	-	64.3(58.9-69.8)
31	-	-	-	-	20.0(26.4-15.9)

[a]Data are presented as percent of plants infested averaged over weekly periods.
[b]Confidence intervals given in parentheses. Weekly infestations are significantly different ($p < 0.05$) if confidence intervals do not overlap.
[c]Number of fields checked at each location each year.
[d]Indicates the week when silking began.

increase in infestation. Also, a peak trap capture period occurred during this time (Fig. 5). The small corn earworm larval infestation continued to increase at Lubbock through day 195.

Emergence Monitoring. Corn earworm adult emergence from pupae excavated from corn fields at LRGV (1988, 1989, 1990), Uvalde (1989, 1990) and Lubbock (1990) is presented in Table 2. At LRGV, adult emergence extended from days 156-180 and 159-180

TABLE 2. Emergence of Corn Earworm Adults from Pupae Excavated from Commercial Corn Fields at LRGV, Uvalde and Lubbock Texas.

End of three day period	Cumulative percent emergence[a]					
	LRGV			Uvalde		Lubbock
	1988 (90)[b]	1989 (100)	1990 (100)	1989 (40)	1990 (40)	1990 (6)
144	-	-	1.2	-	-	-
147	-	-	3.8	-	-	-
150	-	-	12.7	-	-	-
153	-	-	33.1	-	-	-
156	0.4	-	57.7	-	-	-
159	0.4	1.4	76.5	-	-	-
162	3.8	9.9	85.8	-	-	-
165	15.5	31.3	90.8	-	-	-
168	45.5	51.1	96.5	-	-	-
171	70.1	75.0	98.5	-	-	-
174	93.9	92.6	100.0	3.8	0.7	-
177	97.7	99.1	-	14.7	5.1	-
180	100.0	100.0	-	29.3	18.4	-
183	-	-	-	48.4	40.4	-
186	-	-	-	60.3	63.2	-
189	-	-	-	71.2	69.9	-
192	-	-	-	82.6	91.2	-
195	-	-	-	95.7	95.6	-
198	-	-	-	100.0	99.3	-
201	-	-	-	-	100.0	-
204	-	-	-	-	-	-
207	-	-	-	-	-	-
210	-	-	-	-	-	-
213	-	-	-	-	-	-
216	-	-	-	-	-	-
219	-	-	-	-	-	-
222	-	-	-	-	-	-
225	-	-	-	-	-	4.2
228	-	-	-	-	-	12.5
231	-	-	-	-	-	31.3
234	-	-	-	-	-	60.4
237	-	-	-	-	-	85.4
240	-	-	-	-	-	100.0

[a]LRGV 1988, n = 264; 1989, n = 352; 1990, n = 260
Uvalde 1989, n = 184; 1990, n = 136
Lubbock 1990, n = 48

[b]Number of fields excavated.

in 1988 and 1989, respectively. There was no significant difference in the emergence profiles at LRGV for these two years (D_{max} = 0.158, $\alpha_{.05}$ = 0.41). In 1990, adult emergence (days 144-174) occurred significantly earlier than either 1988 (D_{max} = 0.820, $\alpha_{.01}$ = 0.432) or 1989 (D_{max} = 0.759, $\alpha_{.01}$ = 0.418). Adult emergence at Uvalde in 1989 was initiated on day 174 when 92.6% of emergence had occurred at LRGV. A comparison of 1990 emergence profiles shows that 100% emergence had occurred at LRGV when the initial emergence was occurring at Uvalde. There was no significant difference in the 1989 and 1990 emergence profiles at Uvalde (D_{max} = 0.109, $\alpha_{.05}$ = 0.409). Adult emergence at Lubbock extended from days 225-240, about 24 days after the termination of emergence at Uvalde and 51 days after the termination at LRGV.

Meteorological Observations. Our studies show that certain population events occurring within a region may be synchronized with other events such as trap capture peaks, larval infestations and adult emergence within other regions. However, these data do not indicate that interregional movement has actually occurred. Indeed, much of our data suggest that population events within a region could be largely explained in relation to phenology of the local corn crop. However, simulated nocturnal trajectories provide a mechanism for determining if atmospheric systems are available to transport moths from one region to another.

When simulated trajectories originating at LRGV (26.2° N, 98.0° W) in 1988 were averaged over the entire emergence period, the first and second night endpoint coordinates were 28.3° N, 100.3° W and 30.8° N, 101.5° W, respectively (Table 3). A similar pattern was observed in 1989 when the endpoints after one and two nights of simulated flight were 28.8° N, 99.5° W and 30.8° N, 100.4° W, respectively. Both years, the average northward transport was about 255 km from the point of origin after one night and about 510 km after two nights. The maximum northward transport in 1988 for one and two nights was about 540 and 1082 km, respectively. A similar trend was observed in 1989.

In 1990, the atmospheric transport systems were stronger than observed in 1988 or 1989. One and two night trajectory endpoint coordinates averaged 31.1° N, 99.7° W and 35.4° N, 100.1° W, respectively. Thus, moths would have been transported an average of about 540 and 1020 km after one and two nights, respectively. Maximum northward transport in 1990 after one and two nights was about 825 and 1,600 km, respectively.

The average endpoint coordinates of simulated flight trajectories originating at Uvalde (29.2° N, 99.7° W) in 1989 after one and two nights of transport were 31.6° N, 100.4° W and 33.7° N, 100.2° W, respectively. Thus moths originating at Uvalde could have been transported about 260 and 500 km northward after one and two nights, respectively. Maximum northward transport from Uvalde in 1989 after one and two nights was 650 and 1,300 km, respectively. Although the maximum northward transport in 1990 from Uvalde was similar to 1989, the average transport was stronger as observed at LRGV also. The average endpoint coordinates for transport in 1990 from Uvalde were 33.2° N, 100.6° W and 36.7° N, 100.2° W after one and two nights, respectively.

Trajectories calculated from Lubbock (33.5° N, 101.8° W) in 1990 indicated average endpoint coordinates of 37.0° N, 101.1° W and 40.1° N, 99.0° W after one and two nights, respectively. Northward transport averaged about 387 km after one night and 730 km after two nights, respectively.

TABLE 3. Longitude and Latitude Endpoints of Simulated Flight Trajectories of Migrating Corn Earworm Adults after One and Two Nights of Flight from Point of Origin[a].

Variable[b]	Minimum	Maximum	Mean	Standard deviation
		LRGV 1988[c]		
Lon1	96.72	102.58	100.27	1.43
Lat1	21.15	31.08	28.34	2.35
Lon2	95.86	106.10	101.49	2.64
Lat2	18.91	35.95	30.83	4.26
		LRGV 1989[c]		
Lon1	96.03	102.49	99.53	1.62
Lat1	23.34	31.99	28.80	2.60
Lon2	95.15	105.32	100.37	2.84
Lat2	23.15	37.32	30.78	4.06
		LRGV 1990[c]		
Lon1	96.35	102.30	99.68	1.57
Lat1	26.55	33.64	31.06	1.68
Lon2	94.90	105.32	100.04	3.11
Lat2	29.55	40.74	35.41	2.77
		UVALDE 1989[c]		
Lon1	96.53	104.17	100.40	1.95
Lat1	27.07	35.08	31.55	2.24
Lon2	93.68	107.20	101.14	3.79
Lat2	27.24	41.16	33.69	3.60
		UVALDE 1990[c]		
Lon1	98.42	104.38	100.60	1.56
Lat1	29.07	35.95	33.18	1.74
Lon2	94.74	108.76	100.20	3.80
Lat2	28.94	41.13	36.73	3.48
		LUBBOCK 1990[c]		
Lon1	97.46	105.67	101.11	2.39
Lat1	34.98	39.67	36.99	1.16
Lon2	93.58	107.83	99.90	4.05
Lat2	36.99	43.32	40.10	1.84

[a]Data Were Calculated for Adult Emergence Periods.
[b]Lon1 and Lat1 represent the longitude and latitude endpoints after one night of flight. Lon2 and Lat2 represent the longitude and latitude endpoints after two nights of flight.
[c]Points of origin for simulated trajectories.

Anomalous values of atmospheric variables on dates of peak trap capture of corn earworm males at LRGV are presented in tables 4-6 for 1988-1990. The peak values of average daily trap capture for all three years were significantly different from the averages of values within two days of the date of peak capture. None of the anomalous values of the independent variables were significantly associated with the anomalous value of peak capture. Summaries of surface synoptic weather maps documented frequent frontal passages and a southerly wind component on or within one day of the dates of peak capture of corn earworm males in pheromone traps at LRGV. A cold front

TABLE 4. Anomalous Values[a] of Atmospheric Variables on Dates of Peak Trap Capture of Corn Earworm Males in Pheromone Traps in the Lower Rio Grande Valley for 1988 (N = 6).

Variable[b]	Mean	Standard error	t-score
Avg. daily capture (moths/trap)[*c]	32.4	3.68	2.54
Min. surface air temp.	-1.6	1.60	-0.88
Avg. surface air temp.	-1.4	1.08	-1.16
Avg. air temp. at 500 m AGL	0.2	0.97	0.15
Avg. zonal wind speed (500 m AGL)	0.6	0.36	0.69
Avg. meridional wind speed (500 m AGL)	-0.5	3.31	-0.13

[a]An anomalous value is defined as the value on the date of peak capture minus the average of the values on the two dates before and after the peak capture dates.
[b]Temperatures are in degrees Celsius; wind speeds are in meters per second.
[c]*Indicates mean is significantly different from zero at P=0.05.

TABLE 5. Anomalous Values[a] of Atmospheric Variables on Dates of Peak Trap Capture of Corn Earworm Males in Pheromone Traps in the Lower Rio Grande Valley for 1989 (N = 10).

Variable[b]	Mean	Standard error	t-score
Avg. daily capture (moths/trap)[*c]	54.7	10.84	2.76
Min. surface air temp.	0.1	0.70	-0.05
Avg. surface air temp.	-0.4	0.95	-0.19
Avg. air temp. at 500 m AGL	0.0	0.78	0.01
Avg. zonal wind speed (500 m AGL)	0.3	0.43	0.38
Avg. meridional wind speed(500 m AGL)	-0.4	1.97	0.20

[a]An anomalous value is defined as the value on the date of peak capture minus the average of the values on the two dates prior to and two dates after the date of peak capture.
[b]Temperatures are in degrees Celsius; wind speeds are in meters per second.
[c]*Indicates mean is significantly different from zero at P=0.05.

TABLE 6. Anomalous Values[a] of Atmospheric Variables on Dates of Peak Trap Capture of Corn Earworm Males in Pheromone Traps in the Lower Rio Grande Valley for 1990 (N = 10).

Variable[b]	Mean	Standard error	t-score
Avg. daily capture (moths/trap)*[c]	21.0	2.71	3.02
Min. surface air temp.	-0.9	0.86	-0.38
Avg. surface air temp.	0.3	0.59	0.19
Avg. air temp. at 500 m AGL	-0.2	0.41	-0.11
Avg. zonal wind speed (500 m AGL)	0.7	0.52	-0.99
Avg. meridional wind speed (500 m AGL)	-2.3	2.50	-0.69

[a]An anomalous value is defined as the value on the date of peak capture minus the average of the values on the two dates prior to and two dates after the date of peak capture.
[b]Temperatures are in degrees Celsius; wind speeds are in meters per second.
[c]*Indicates mean is significantly different from zero at P=0.05.

passed the LRGV within one day of the peak capture date on 67%, 64% and 50% of the dates of peak capture of corn earworm in 1988, 1989 and 1990, respectively. Minimum air temperatures ≤ 15.6° C was reported for 67%, 46% and 60% of the cases of peak captures in 1988, 1989 and 1990, respectively.

Anomalous values of peak capture at Uvalde in 1990 were not significantly different ($P > 0.05$) (Table 7). The anomalous value of the average meridional wind speed at 500 m AGL was the only independent variable that was significant ($P < 0.05$). The significant difference showed a 3.8 m/sec stronger southerly wind component on peak capture dates than on dates within two days of peak capture. The small number of dates (three) suggests that this relationship may change if more dates were included in the analysis. Summaries of synoptic maps indicated a warm sector over central Texas and a minimum air temperature ≥ 24.4° C on each of three dates of peak capture at Uvalde.

Daily trap captures on selected peak dates in 1990 at Lubbock were not significantly different ($P > 0.05$) from the average values within two days of the peak (Table 8). The average zonal wind speed at 500 m AGL was the only significant independent variable averaging 2.7 m/sec greater on peak capture dates compared to average values within two days of the peak. Zonal wind speed at Lubbock had a 1.3 m/sec westerly component instead of moderate easterly easterly component (-4.0 m/sec). Synoptic weather summaries indicated that cold fronts, warm fronts and upper-level troughs of low pressure, passed Lubbock, Texas, on 37%, 13% and 25%, respectively, of dates of peak capture of corn earworm males in pheromone traps in 1990. A warm sector with a southerly wind component was located over Lubbock on the remaining 25% of the dates of peak capture.

TABLE 7. Anomalous Values[a] of Atmospheric Variables on Dates of Peak Trap Capture of Corn Earworm Males in Pheromone Traps at Uvalde 1990 (N = 3).

Variable[b]	Mean	Standard error	t-score
Avg. daily capture (moths/trap)	27.2	5.05	2.27
Min. surface air temp.	1.6	0.49	2.54
Avg. surface air temp.	0.8	0.27	0.77
Avg. air temp. at 500 m AGL	-0.6	0.25	-0.87
Avg. zonal wind speed (500 m AGL)	-1.4	0.64	-1.84
Avg. meridional wind speed (500 m AGL)*[c]	3.8	0.39	4.53

[a]An anomalous value is defined as the value on the date of peak capture minus the average of the values on the two dates before and after the peak capture dates.
[b]Temperatures are in degrees Celsius; wind speeds are in meters per second.
[c]*Indicates mean is significantly different from zero at P=0.05.

TABLE 8. Anomalous Values[a] of Atmospheric Variables on Dates of Peak Trap Capture of Corn Earworm Males in Pheromone Traps at Lubbock, Texas, for 1990 (N = 7).

Variable[b]	Mean	Standard error	t-score
Avg. daily capture (moths/trap)	82.1	19.54	1.38
Min. surface air temp.	1.6	0.83	1.80
Avg. surface air temp.	1.2	0.47	1.00
Avg. air temp. at 500 m AGL	0.8	0.45	0.69
Avg. zonal wind speed (500 m AGL)*[c]	2.7	0.68	2.37
Avg. meridional wind speed (500 m AGL)	2.2	1.23	0.97

[a]An anomalous value is defined as the value on the date of peak capture minus the average of the values on the two dates before and after the peak capture dates.
[b]Temperatures are in degrees Celsius; wind speeds are in meters per second.
[c]*Indicates mean is significantly different from zero at P=0.05.

DISCUSSION

Ecologically, our data show that corn earworm larval infestation on fruiting corn and adult emergence from fruiting corn provide relatively discreet population events that are well separated on a regional basis. This precision is driven primarily by the phenology of the corn plant (*viz*, silking). In most instances trap capture of adults appears, on a local scale, to be related to these two events. However, the variability observed in trap capture in early season as well as larval infestations on vegetative corn within regions provide difficulty in temporally defining the occurrence of meaningful events related to these variables across regions. Corn is one of the earliest planted crops in most regions, and corn earworm populations infesting vegetative corn may be a composite population consisting of overwintering and migrating components. Thus, the variability in spring time atmospheric conditions (fluctuating temperature and wind patterns associated with frontal movements) (Muller and Tucker 1986, Wolf et al. 1986, John K. Westbrook personal communication) that provide the transport vehicle for migrating adults may add substantially to the variability observed in regional populations during the vegetative growth stage of corn. Indeed, the relationship between trap capture and regional population fluctuations is not understood.

Considering the maximum and minimum coordinates of the simulated flight trajectories, migrating moths arising from maturing corn in the LRGV over the three years of observations could have been distributed between longitudes ranging from 94.9 to 106.1° W and latitudes ranging from 18.9 to 40.7° N. This area would encompass most of Texas, Oklahoma, and Kansas as well as portions of Nebraska, Colorado, New Mexico and Mexico. The distribution from Uvalde would encompass the same region from a latitude of 27.1 northward. The distribution from Lubbock in 1990 could have extended from the panhandle of Texas northeast to Iowa and northwest to Nebraska. These data indicate the magnitude of dispersal that can occur from relatively concentrated source areas. They also suggest that due to dispersal, large concentrations of immigrants may not always occur in given recipient zones. Thus, population events such as trap capture peaks or larval infestation peaks associated with the migrant may be difficult to detect.

Our results showed only minor correlation between daily trap captures of corn earworm and air temperature and wind velocity. This implies that trap capture values did not abruptly increase with either significantly warmer or cooler temperatures or with increased or decreased zonal or meridional wind speed. We conclude that the atmospheric conditions described here as independent predictor variables had no significant influence on the response of corn earworm males to pheromone traps or on the long-distance atmospheric transport of populations into the trapping area. However, trap capture can be influenced by other biological and physical parameters such as adult behavior related to population age structure (Raulston et al. 1979), magnitude and timing of populations developing on both cropped and noncropped hosts, host phenology, adult redistribution on a local basis (Hagis 1982), frontal movements, storms, temperature and wind extremes. Such influences on the local scale may conceal the effects of atmospheric conditions relating to long distance translation of moth populations. Thus, inter-regional influences resulting from adult migration will be difficult to ascertain based on adult trapping. The relative uniformity of adult emergence from fruiting corn provides a "time window" for coordinating atmospheric transport studies synchronized with the emergence. Indeed, Westbrook et al. (1994) used radio transmitters attached to mylar balloons (tetroons), tracking vehicles and mobile ground based radars, to determine the movement of corn earworm moths emerging and dispersing from the corn production region north of Lubbock, Tex. They showed that corn earworm dispersing from this region were transported as far north as Oklahoma, southwest Kansas and southeast Colorado in one night. They also showed a high variability in insect headings that contributed substantially to a lateral dispersal of the migrating populations. Ecological and meteorological studies coupled with ground based and airborne entomological radar observations provide an holistic approach to determining when migration occurs and defining the variables that impact the migratory process. However, additional studies including detection of natural markers such as pollens, (Hendrix III et al. 1987, Bryant et al. 1991, Hendrix III and Showers 1992, Lingren et al. 1993) and large scale marking of individuals in source areas and their subsequent detection in recipient areas are required to determine the impact of migrants on local population dynamics.

LITERATURE CITED

Birnbaum, Z. W. 1952. Numerical tabulation of the distribution of Kolmogorov's statistic for finite sample size. J. Am. Stat. Assoc. 47: 425.

Bryant, V. M., M. Pendleton, R. E. Murray, P. D. Lingren and J. R. Raulston. 1991. Techniques for studying pollen adhering to nectar-feeding corn earworm (Lepidoptera: Noctuidae) moths using scanning electron microscopy. J. Econ Entomol. 84: 237-240.

Drake, V. A. 1984. The vertical distribution of macro-insects migrating in the nocturnal boundary layer: a radar study. Boundary-Layer Meteorol. 28: 353-374.

Drake, V. A. 1985. Radar observations of moths migrating in a nocturnal low-level jet. Ecol. Entomol. 10: 259-265.

Drake, V. A. and R. A. Farrow. 1988. The influence of atmospheric structure and motions on insect migration. Ann. Rev. Entomol. 33: 183-210.

Farrow, R. A. and J. C. Daly. 1987. Long-range movement as an adaptive strategy in the genus *Heliothis* (Lepidoptera: Noctuidae): A review of its occurrence and detection in four pest species. Aust. J. Zool. 35: 1-24.

Garman, H. and G. G. Jewett. 1914. The life history and habits of the corn earworm (*Chloridea obsoleta*). Kent. Agric. Expt. Stn. Bull. No. 187.

Hackett, D. S. and A. G. Gatehouse. 1982. Studies on the biology of *Heliothis* spp. in Sudan, pp. 29-38. *In* W. Reed and V. Kumble (eds.). Proc. Int. Workshop on *Heliothis* Management, International Crops Research Institute for the Semi-arid Tropics (ICRISAT), 15-20 Nov. 1981, Patancheru, A. P., India.

Haggis, M. J. 1982. Distribution of *Heliothis armigera* eggs on cotton in the Sudan Gezira: spatial and temporal changes and their possible relation to weather, pp. 87-99. *In* W. Reed and V. Kumble [eds.]. Proc. Int. Workshop on

Heliothis Management, International Crops Research Institute for the Semi-arid Tropics (ICRISAT), 15-20 Nov. 1981, Patancheru, A. P., India.

Hartstack, A. W., Jr., J. R. Witz and D. R. Buck. 1979. Moth traps for the tobacco budworm. J. Econ. Entomol. 72: 519-522.

Hendrix, W. H., III, T. F. Mueller, F. R. Phillips, and O. K. Davis. 1987. Pollen as an indicator of long-distance movement of *Heliothis zea* (Lepidoptera: Noctuidae). Environ. Entomol. 16: 1148-1151.

Hendrix. W. H., III, and W. B. Showers. 1992. Tracing black cutworm and armyworm (Lepidoptera: Noctuidae) northward migration using *Pithecellobium* and *Calliandra* pollen. Environ. Entomol. 21: 1092-1096.

Joyce, R. J. V. 1982. A critical review of the role of chemical pesticides. pp. 173-188. *In* W. Reed and V. Kumble [eds.]. Proc. Int. Workshop on *Heliothis* Management, International Crops Research Institute for the Semi-arid Tropics (ICRISAT), 15-20 Nov. 1981, Patancheru, A. P., India.

Knipling. E. F. 1979. The basic principles of insect population suppression and management. U.S. Dept. Agric., Handbook No. 512.

Lingren, P. D. and W. W. Wolf. 1982. Nocturnal activity of the tobacco budworm and other insects, pp. 211-228. *In* J. L. Hatfield and I. J. Thomason (eds.). Biometeorology in Integrated Pest Management. Academic Press, New York.

Lingren, P. D., V. M. Bryant, Jr., J. R. Raulston, J. K. Westbrook, and G. D. Jones. 1993. Adult feeding host range and migrating activities of corn earworm, cabbage looper and celery looper (Lepidoptera: Noctuidae) moths as evidenced by attached pollen. J. Econ. Entomol. 86: 1429-1439.

Muller, R. A. and N. L. Tucker. 1986. Climatic opportunities for the long-range migrations, pp. 61-83. *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. U. S. Dept Agric., ARS-43.

Pepper, B. H. 1943. The relationship between cropping practices and injury by *Heliothis armigera* with special reference to lima beans and tomatoes. J. Econ. Entomol. 36: 329-330.

Quaintance, A. L. and C. T. Brues. 1905. The cotton bollworm. U.S. Dept. Agric. Bur. Entomol. Bull. No. 50.

Raulston, J. R., P. D. Lingren, A. N. Sparks and D. F. Martin. 1979. Mating interaction between native tobacco budworms and released backcross adults. Environ. Entomol. 8: 349-353.

Raulston, J. R., S. D. Pair, F. A. Pedraza-Martinez, J. K. Westbrook, A. N. Sparks and V. M. Sanchez Valdez. 1986a. Ecological studies indicating the migration of *Heliothis zea*, *Spodoptera frugiperda*, and *Heliothis virescens* from northeastern Mexico and Texas, pp. 204-220. *In* W. Danthanarayana (ed.). Insect Flight Dispersal and Migration. Springer-Verlag, Berlin.

Raulston, J. R., S. D. Pair, A. N. Sparks, J. K. Westbrook, J. Loera, K. R. Summy and D. R. Rummel. 1986b. Production of *Heliothis zea* on corn in northeastern Mexico and the Lower

Rio Grande Valley of Texas: A potential source for corn and cotton infestation on the High Plains. Beltwide Cotton Production Research Conferences. pp. 222-225, *In* Proc. Beltwide Cotton Conf., Cotton Council Amer.

Raulston, J. R., K. R. Summy, J. Loera, S. D. Pair and A. N. Sparks. 1990. Population dynamics of corn earworm larvae (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.

Stinner, R. E., K. Wilson, C. Barfield, R. Regniere, A. Riordan, and J. Davis. 1982. Insect movement in the atmosphere, pp. 193-209. *In* J. L. Hatfield and I. J. Thomason [eds.]. Biometeorology in Integrated Pest Management. Academic Press, Inc. New York.

Westbrook, J. K., C. T. Allen, F. W. Plapp Jr., and W. Multer. 1990. Atmospheric transport and pyrethriod resistant tobacco budworm, *Heliothis virescens* (Lepidoptera: Noctuidae), in western Texas in 1985. J. Agric. Entomol. 7: 91-101.

Westbrook, J. K., W. W. Wolf, P. D. Lingren, and J. R. Raulston. 1994. Flight speed and heading of migrating corn earworm moths relative to drifting tetroons, pp. 423-426. In Proc. 11th Conference on Biometeorology and Aerobiology. Amer. Meteorol. Soc. Mar. 7-11, 1994. San Diego, CA.

Wolf, W. W., J. K. Westbrook and A. N. Sparks. 1986. Relationship between radar entomological measurements and atmospheric structure in south Texas during March and April 1982, pp. 84-97, *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. U. S. Dept. Agric., ARS-43.

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* Proc. of the Roal Soc., Migrant Pests: Problems, Potentialities and Progress. University Press, Cambridge, England.