FLIGHT PHENOLOGY AND PHEROMONE TRAPPING OF *SPODOPTERA EXIGUA* (HÜBNER) (LEPIDOPTERA: NOCTUIDAE) IN SOUTHERN COASTAL CALIFORNIA

JOHN T. TRUMBLE AND THOMAS C. BAKER

Made in United States of America
Reprinted from ENVIRONMENTAL ENTOMOLOGY
Vol. 13, No. 5, October 1984

Flight Phenology and Pheromone Trapping of *Spodoptera exigua* (Hübner) (Lepidoptera: Noctuidae) in Southern Coastal California

JOHN T. TRUMBLE AND THOMAS C. BAKER

Department of Entomology, University of California,
Riverside, California 92521

Environ Entomol 13: 1278–1282 (1984)

ABSTRACT A standard wing trap was significantly more effective at capturing *Spodoptera exigua* (Hübner) males than a delta trap, a cone-orifice trap, an omnidirectional trap, or a modified omnidirectional trap. No significant differences in collections from wing traps were evident when the two-component pheromone was formulated in polyethylene caps or in 3, 10, or 15 hollow fiber dispensers Mean numbers of moths captured in wing traps containing 10-fiber dispensers aged for up to 1 month in the field were not significantly different from numbers collected in traps with fresh dispensers. Pheromone trap collections from San Diego, Orange, and Ventura counties demonstrated that *S. exigua* flight activity was bimodal in California, with peak flights occurring from April to June and again from August until early December. Analysis of wind direction, velocity, and temperatures at heights up to 3,000 m showed that moths could not migrate into southern California before or during peak flight periods in the spring, indicating that *S exigua* was overwintering in these areas

THE BEET ARMYWORM (BAW), *Spodoptera exigua* (Hübner), is a polyphagous noctuid which has achieved primary pest status on a variety of agriculturally important plants in the United States, Europe, and the Middle East (Oatman and Platner 1972, French 1969, Schwartz et al. 1980). A combination of factors, including a lack of information on population dynamics (Hogg and Gutierrez 1980) and migration patterns (Mitchell 1979), as well as an apparent potential for developing resistance to pesticides (Poe et al 1973, Meinke and Ware 1978), has contributed to control failures resulting in economically damaging populations in the continental United States. One objective of this study was therefore to provide more information on population dynamics and migration patterns of BAW by documenting flight phenology in southern California.

Sex pheromone traps can provide a realistic estimate of the beginning and end points of male emergence, flight activity, and migration (Riedl et al. 1976). Fortunately, both sexes of BAW reportedly disperse together in nearly equal numbers (French 1969), allowing pheromone trap catches to approximate population shifts associated with sequential generations. In order to maximize the effectiveness of this trapping technique for monitoring population dynamics of BAW, selected pheromone dispensing systems and trap designs were assessed both for effectiveness and utility.

Methods and Materials

Evaluation of Trap Design. Five trap designs were evaluated: a wing trap (Pherocon IC, Albany Wing Style Trap), an omnidirectional trap (Sharma et al. 1973), an omnidirectional trap modified by the addition of one-way insect barriers, a cone-orifice trap (Struble 1983) manufactured by Hara Ltd. and a delta trap. The one-way insect barriers used in the modified omnidirectional trap were constructed by cutting an X in the bottom of plastic 29.6-ml dairy creamer cups, pushing the bottom panels outward and cementing the barriers to the trap. This design allowed the moths to force themselves into the trap, but prevented exiting.

All trap designs except the delta style were evaluated for 31 weeks in tomatoes on trellises in San Diego County, 24 weeks in celery in Ventura County, and 16 weeks on tomatoes in Orange County, Calif., during 1982 to 1983. Celery and tomatoes were selected as experimental crops, because BAW is a major pest on both, and together these crops provided a continuous system available at all three sample locations. Ten replicates of each trap were arranged in a randomized complete block design, separated by at least 10 m and suspended from wooden stakes just above the foliage. Each week, numbers of moths were recorded and traps were rerandomized; pheromone dispensers were changed no less than every other week. Delta traps were tested for 7 weeks in tomatoes and 5 weeks in celery in Orange County, Calif., during 1983. Experimental designs were the same as in the previous test.

All statistical analyses were made between traps tested concurrently within each site to remove variation from population fluctuations or environmental factors prevalent at only one location. Data were first checked for normalcy (Proc Univariate program of the Statistical Analysis System [Helwig and Council 1979]). Because a few individual traps

Table 1. Efficiency of selected traps for capturing adult *S. exigua* males

Trap substrate	Weeks of evaluation	Wing		Standard omnidirectional		Modified omnidirectional		Cone-orifice		Delta	
		$\bar{x}$	(Max)	$\bar{x}$	(Max)	$\bar{x}$	(Max)	$\bar{x}$	(Max)	$\bar{x}$	(Max)
Tomatoes	31	16 1a	(103)	11.7b	(63)	8.1c	(103)	8 2c	(74)	—	—
Celery	24	8 5a	(68)	3 9b	(53)	1.8c	(46)	2 5bc	(33)	—	—
Tomatoes	16	8.1b	(54)	8 5b	(58)	17.2a	(370)	5.1b	(39)	—	—
Tomatoes	7	43 3a	(120)	—	—	—	—	—	—	44.8a	(111)
Celery	5	41 6a	(90)	—	—	—	—	—	—	34.2b	(58)

Ten replicates of each trap were monitored each week, means in rows followed by the same letter are not significantly different ($P < 0.05$; Duncan's multiple range test)

were damaged or lost, an ANOVA designed for unequal sample size was used for the analyses. BAW pheromone components for the trap design experiments were formulated in polyethylene caps (vial closures), 1.9 cm wide by 1.2 cm high having a removable lid. The pheromone blend (Tumlinson et al. 1981, Mitchell et al. 1983), at the concentrations 100 µg (*Z,E*)-9,12-tetradecadienyl acetate (Shin Etsu Chemical Co., Ltd.) plus 10 µg (*Z*)-9-tetradecenyl alcohol, was loaded into the hollow interior of each cap in 10 µl hexane. Polyethylene lids were snapped in place to seal the caps after the solvent had evaporated. Although a different pheromone formulation was available (Persoons et al. 1981) and would have been as effective at capturing males (Persoons and Baker, unpublished), the more easily formulated two-component blend was utilized.

Pheromone Dispensing Systems. Polyethylene caps (prepared as mentioned previously) were compared with commercially produced 3, 10, and 15 hollow fiber dispensers (Albany International) containing the same pheromone blend. Five replicates of each dispenser were tested in wing traps which were arranged in a randomized complete block design in a celery field in Ventura County, Calif. Each week for 12 consecutive weeks the number of moths was recorded, treatments were rerandomized, and pheromone dispensers were replaced. A longevity study of the cap dispensers was included in this test, with moth catches from field-aged caps 1 and 2 weeks old compared with fresh caps and hollow fiber dispensers.

Longevity of attractancy of pheromone in the hollow fiber dispensers was determined in a 13-week experiment in Orange County, Calif., during 1983. Evaluations of fresh and 1- to 4-week-old, field-aged dispensers were made weekly. Again, all treatments were rerandomized each week in a randomized complete block design. Only data from 11 weeks were included in the analysis because high winds and commercial cultural practices destroyed all of the traps on two occasions.

Flight Phenology Study. Occurrence and magnitude of BAW flights were monitored from May 1982 until December 1982 at Oceanside (San Diego County) and from May 1982 through April 1983 at Irvine (Orange County) and Oxnard (Ventura County). At least 5 wing traps, and usually 10 or more traps per county, containing pheromones in cap dispensers were checked weekly. Losses due to inclement weather interfered with catches on three dates at both Ventura and Orange Counties. All traps at Oceanside were placed in commercially grown tomatoes. At Irvine and Oxnard, traps were maintained primarily in commercial celery fields, and only transferred to tomato plantings when celery was unavailable.

Weather data collected from Orange County included daily maximum and minimum temperatures, precipitation, and both nocturnal and diurnal wind velocity and direction. Upper atmospheric temperatures and wind velocities and directions, collected by National Oceanic and Atmospheric Administration installations in San Diego and at Vandenburg Air Force Base, were available from the National Climatic Center in Asheville, N.C. These locations bracketed our study area, providing data on winds moving into or out of the region. High altitude weather readings were made at 150 and 500 to 3,000 millibar pressures (at 500-millibar intervals). These millibar pressures were equivalent, within 8%, to the same values in heights measured in meters. Monthly averages of wind patterns are presented as "vector sums", which were generated by weighting wind direction and wind velocity equally.

Results and Discussion

Evaluation of Trap Design. Wing traps were generally the most effective design tested (Table 1). In four of the five trials, wing trap catches were significantly greater or not significantly less ($P \leq 0.05$) than any of the others. When moth catches were analyzed on a weekly basis, this same trend was evident. In the one test where wing traps caught significantly fewer moths based on an analysis of all 16 weeks (Table 1), weekly comparisons indicated significant differences occurred only during 2 weeks.

The standard omnidirectional trap was the only design which proved ineffective at holding moths that entered the trap. Because the sides and upper surfaces of this trap were not coated with Tack Trap®, moths were not immediately ensnared by

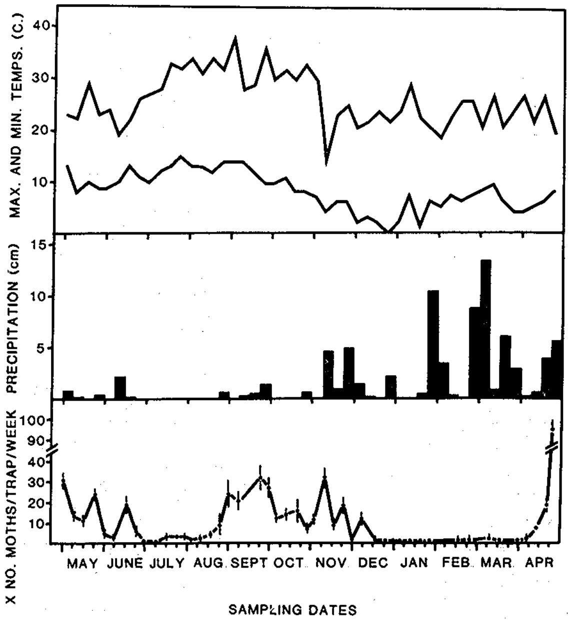

Fig. 1. *S. exigua* flight phenology as related to weekly precipitation and minimum and maximum temperatures in Orange County, Calif., during 1982 and 1983. Brackets on means delineate standard errors.

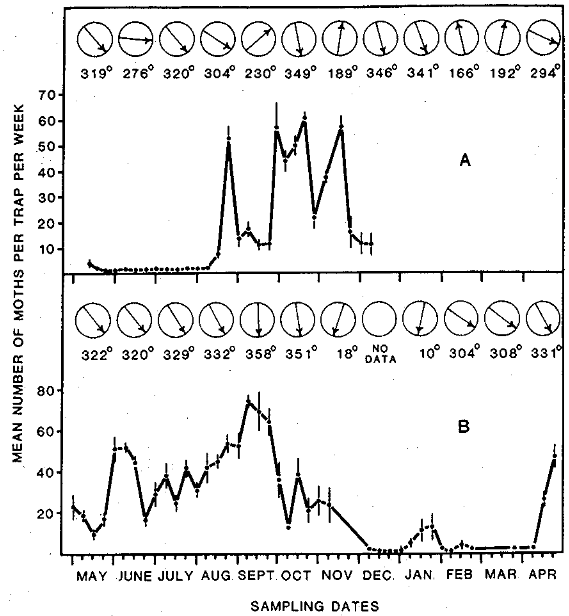

Fig. 2. Flight phenology of *S. exigua* in San Diego (A) and Ventura (B) counties in California during 1982 and 1983. Brackets on means delineate standard errors. Circles with arrows represent monthly wind sources and directions at approximately 150 m presented as vector sums (*see* text) with 360° and 180° representing N and S, respectively.

the trap, and the coated bottom surface rapidly became saturated with moth scales, allowing some insects to escape. The coated surfaces in the modified omnidirectional trap also became saturated with moth scales but the one-way barriers effectively prevented adults from leaving. As a result, this design collected the maximum number of moths found in any trap on one occasion in tomatoes in Orange County (Table 1). However, these barriers may have interfered with the pheromone plume, since this trap design was the least effective in two of three trials. Both the standard and modified omnidirectional traps deteriorated rapidly under field conditions and required frequent replacement.

Pheromone Dispensing Systems. No significant differences in trap catches were evident when cap dispensers were compared with 3, 10, and 15 hollow fiber dispensers ($P \leq 0.05$; Duncan's multiple range test). Mean catch per week for the total 12-week test ranged from 45.2 for the fresh caps to 41.6 for the three-fiber dispensers. A comparison of mean catches within each week also indicated no significant differences between treatments. Pheromone blends in caps which were aged up to 2 weeks in the field were as effective as all other treatments in this test.

Mean moth collections from traps with 10 fiber dispensers ranging from unused to 4 weeks old showed that the hollow fiber dispensers will remain effective for at least 1 month in the field. Means were not significantly different if analyzed over the entire test and the 4-week-old fibers only caught significantly fewer moths on 1 of 11 dates (ranges: low, 0.4–1.6; high, 10.6–19.2).

Flight Phenology. The flight activity periods presented in Fig. 1 and 2 suggest that BAW completes three to five generations in southern or central California. In Ventura and Orange Counties, flight activity was high from April to June, and from August until the first week in December. These results were similar to those reported in Florida (Tingle and Mitchell 1977), except that our bimodal activity periods were less clearly defined.

Observation of a spring flight period in April was in agreement with reports by Fye and Carranza (1973) that emergence of BAW in field cages peaked during late March and early April in Arizona. Since development at 25°C requires ca. 30 days (Fye and McAda 1972), flight peaks occurring about a month apart during these activity periods probably represent sequential generations.

Unfortunately, documentation of a spring flight period was not possible from the incomplete data available from San Diego. However, the late summer to fall activity period was clearly evident. As seen in the other locations, trap catches increased rapidly in August and declined during the latter half of November. During this period at least three generations were discernible (Fig. 2A).

The generally higher level of moth activity evident in Ventura and San Diego Counties as opposed to Orange County can be explained by the variability and extent of agriculture present at each location. Urban encroachment in Orange County has reduced the availability of weed hosts and crop acreage. As a result, high value crops such as lemons and strawberries predominate, with only celery (<405 ha), tomatoes (<405 ha) and cole crops (<1,215 ha) providing major sources of host material for BAW (McGregor et al. 1981). Agriculture in Ventura County supplies more hosts and greater acreage: celery (>4,050 ha), tomatoes (2,025 ha), cole crops (>8,100 ha) and lettuce (>608 ha) are produced throughout the county. San Diego provides approximately 3,240 ha of these hosts, most of which are grown during the late summer and fall (McGregor et al. 1981).

Precipitation and temperature were monitored daily in Orange County (Fig. 1) and correlated with BAW abundance. No significant relationships ($P \leq 0.10$; Pearson's product-moment correlation) were found between either rainfall or maximum/minimum temperatures and collections of BAW. However, these data were analyzed on a weekly basis in order to be comparable to the weekly trap assessments, and a more frequent monitoring of traps (<24-h intervals) might demonstrate significant relationships that could not be proven in our test.

The onset of flight activity in April 1983, in spite of the southerly movement of winds and weather fronts, indicated that BAW was overwintering in coastal California (Fig. 1 and 2). However, because migration on major weather fronts can occur in the span of only a few days (French 1969), weather data from San Diego and Vandenburg Air Force Base were examined for daily trends. Analysis of wind velocities and directions collected daily at 4 p.m. and 4 a.m. showed that wind-mediated migrations of BAW from locations south or east of San Diego were not possible: no combination of wind directions at ground level, or heights of ca. 150 m or 500 to 3,000 m (at 500-m intervals) would have carried BAW to Orange or Ventura Counties.

Immediately (3 weeks) before and during the spring activity period, San Diego data showed no winds arising from an eastern or southern direction at 4 p.m. and only twice did wind arise from the south at 4 a.m. However, on both days 10.6°C for any height was below the 15.6°C minimum flight temperature for BAW reported by Hogg and Gutierrez (1980). Similarly, weather data collected at Vandenburg Air Force Base showed that maximum wind velocity in a northern direction at any height was 6 kph (on only 1 day at 4 a.m.), and that at the heights where these winds occurred (>138 m), temperatures were below 12°C. Even if moths moving north or west could migrate against the wind for extended distances, such migrations would have to be made at low altitudes using optomotor anemotaxis (Kennedy 1951), and the insects would still have to overcome the problems associated with movement through the mountainous terrain (Wellington 1983) surrounding Orange and Ventura Counties on the south and east. Most importantly, we have observed larvae throughout the winter months on commercial vegetables in Orange and Ventura Counties (E. R. Oatman, personal communication; Trumble, unpublished data), and these data combined clearly indicated that BAW flight peaks in the spring were the result of overwintering, indigenous populations.

Acknowledgment

We acknowledge with thanks the help of H. Nakakihara, W. Carson, and J. Feaster in the field, and R. Vetter in the laboratory. Albany International provided the pheromone formulated in the hollow fiber dispensers. The reviews of E. R. Oatman and T. M. Perring have improved this manuscript and are appreciated.

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Received for publication 17 January 1984; accepted 22 May 1984.