MONITORING AND PREDICTION OF HELIOTHIS SPP.[1],[2],[3]

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ABSTRACT

A computer based model, MOTHZV, has been developed for predicting the population dynamics of Heliothis spp. populations. The model uses early season insect numbers (adults, eggs or larvae) to forecast timing and size of later, potentially damaging pest populations. Developments in pheromone identification and design of an efficient pheromone trap have provided the means for measuring early season Heliothis adult numbers. Pheromone trap catches, together with appropriate climatic and crop phenology data, were used as input to the MOTHZV model to predict timing of future Heliothis generations for the pilot test "Management of Heliothis spp. in cotton by augmentative releases of Trichogramma." Pheromone traps were monitored through the remainder of the crop season to provide an additional alert to potential ovipositional periods.

INTRODUCTION

Modeling has developed from man's desire to study and control large, complex systems. Models can unify and guide research, providing an understanding of system interactions and predicting the results of alternative experimental treatments. Insect population models have potential for giving scientists information on phenology and abundance of pests so that better management strategies can be planned.

Although there has been progress in model development and attempts have been made to apply models and other systems analysis techniques directly to production practice, the basic approach to sampling and decision-making for insect control in field crops is largely unchanged over the last 40 yrs. Various methods of sampling pests have been recommended; however, the few methods with low risk for error are laborious and tedious. The effort required to get accurate data (e.g. whole plant inspection for Heliothis eggs and larvae) may make it too expensive for normal production

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use and the extra time involved may delay scheduling of necessary control measures.

Sampling adults with pheromone traps offers potential for providing a two to three day lead-time in estimating pest egg numbers. Considerable progress has been made in identification of Heliothis spp. pheromones (Klun et al. 1979) and in pheromone trap design (Hartstack et al. 1979). Not enough is known about the many factors that affect moth capture in pheromone baited traps to permit an accurate estimate of moth numbers on a field by field basis; however, during early season (March-June in the cotton belt), estimation of moth numbers can be made on an area or regional basis (Hartstack and Witz 1981). Even if the actual number of moths in individual fields cannot currently be determined, potential oviposition may be anticipated by trap catches one to three days before detection is possible by sampling eggs in the field. These extra days can enable more efficient scheduling of egg sampling for validation and allow proper consideration of management alternatives.

An accurate prediction of when, where, and how many pests will be present would be a tremendous contribution to the successful operation of a pest management system. A prediction program in Texas (Hartstack et al. 1977), using pheromone traps for the corn earworm (CEW)(cotton bollworm, tomato fruitworm), Heliothis zea (Boddie), and the tobacco budworm (TBW), Heliothis virescens (F.), and the model, MOTHZV, has proven successful in predicting timing of future generations of these species which infest cotton. A comparable program, using pheromone traps and the MOTHZV model, was incorporated into the pilot test "Management of Heliothis spp. in cotton by augmentative releases of Trichogramma pretiosum" (see King et al., this monograph, for complete pilot test description).

METHODS AND MATERIALS

Pheromone Traps for Sampling Adults. Forty "75-50" cone pheromone traps (Hartstack et al. 1979) were installed in a ca. 52,000 ha area around Portland, AR, in 1981 and 1982. Twenty traps were baited for CEW and 20 were baited for TBW. Pheromone components used were those described by Klun et al. (1979) and were laminated between layers of plastic (Hercon Div., Health-Chem Corp., N.Y., NY). The baits contained four components at concentrations of 0.4 mg/cm^2 and seven components at 6.4 mg/cm^2, for CEW and TBW respectively. About 3.2 cm^2 of the laminated plastic formulation was used as bait in each case.

Traps in Arkansas were installed on March 18 in 1981 and on March 1 in 1982 with at least one trap for each species located along accessible field margins, roadways and fence lines near each field monitored for pests. Traps were serviced three times/wk in 1981 and daily in 1982 except for a few weekends. Traps were rebaited every two wks.

Twenty "75-50" cone pheromone traps were installed in a ca. 5,200 ha area around Kitty Fork, NC, in 1983. Ten traps were baited for CEW and 10 for TBW. Bait used was the same type as used in Arkansas. Traps were installed on April 4 with one trap for each species being located adjacent to test fields. Traps were serviced three times/wk except for May in which they were checked five times/wk.

Sampling Heliothis Abundance. All samples of eggs and larvae were taken by the whole plant examination method (see King et al., this monograph, for complete sampling description). Fields were sampled every three to four days throughout the growing season. Egg counts were interpolated to daily values and averaged over all fields for comparison to trap catch and predictions.

Samples of larvae were counted by size category and reared on artificial diet until adult emergence to determine species. Larval ages were estimated from size categories and equalized by projecting all sample dates back to the egg stage. Sample counts, adjusted for date, were then used to calculate the proportions of CEW in the total Heliothis spp. population.

Prediction of Future Generations by Model. MOTHZV, a model of Heliothis zea and H. virescens population dynamics, (Hartstack et al. 1976b and Hartstack and Witz 1983), computes developmental, mortality, and ovipositional rates for CEW and TBW, based on temperature and crop phenology. Using these factors, the model predicts the timing and number of individuals advancing through each life stage. Elementary crop models are included for corn and cotton which predict the basic phenology of the crop over time.

Calculations in the model must be initialized with the daily number of individuals in one life stage (eg. adults or eggs) over a generation. Acquiring this data is often a major problem in applying insect population models; however, the pheromone trap is able to provide the necessary information for Heliothis spp. (Hartstack and Witz 1981). A requirement for prediction of the first oviposition of the season, using MOTHZV, is to have traps in operation early enough to monitor the first CEW and TBW adults present in the spring, either from diapause emergence or migration.

With the monitoring program in place, the only other data needed for MOTHZV are the planting dates for the host crop and maximum-minimum air temperatures. Temperature data for the local area, up to the day of a simulation, were obtained from the pilot test cooperators. Long term daily average maximum-minimum temperatures were used as a prediction of future temperatures from the day of simulation to the end of the season. Historical temperatures were obtained from the USDA Laboratory at Stoneville, MS, to use in simulations for Portland, AR; data taken at Clinton, NC, as obtained from NOAA National Climatic Data Center records, were used in simulations for Kitty Fork, NC.

A preliminary simulation with MOTHZV for Portland, AR in 1981 was made on May 11. The prediction indicated that CEW moths of the first generation would begin emerging on May 20; therefore, moths captured before this date likely emerged from diapause or migrated into the area. For Arkansas in 1982, the preliminary simulation was made on May 18 and the prediction indicated that the first generation would not begin emerging until May 25. A simulation on May 18, 1983 for North Carolina indicated that the first generation of CEW adults would begin to emerge after June 22. Long term temperature records indicate that the test area of North Carolina is cooler on average than the test area in Arkansas in the spring and 1983 temperatures ran below normal in North Carolina, so Heliothis spp. populations in North Carolina ran about one generation later than in Arkansas the previous two years.

After the first generation had been monitored and the predictions made, updated simulations were made as more input data (i.e. temperature and trap catch) became available. When using MOTHZV it is important to monitor a complete generation before making a simulation. When only a portion of a generation is used to initialize the model, only the corresponding portion of the next generation will be predicted. Major errors in timing estimates will result, if the predicted output is interpreted as a full generation. Therefore, updates of trap catch data were not used unless another complete generation of data was available. Further, trap catch data were only used for initialization through ca. July because, beyond that time, pheromone trap data are not a good measure of insect abundance (Hartstack and Witz 1981).

Separate runs were made for CEW and TBW. Since counts of eggs included both species, CEW and TBW egg predictions were totaled for comparison purposes.

RESULTS AND DISCUSSION

Pheromone Trap Catches. Total trap catches of CEW were greater than TBW in all three years, although the proportion of the two species captured fluctuated through the season each year (Figs. 1C, 2C, and 3C). The species ratio was substantiated by larval collections in 1982 and 1983 (Figs. 2C and 3C). In 1981 and 1983, CEW remained the major species throughout the season, except for short intervals. In 1982, the size of the TBW trap captures was proportionately large enough for TBW to be predominant as the number captured from the two populations cycled out of phase with each other.

Relative cycling of trap catches appeared to differ with location: in Arkansas, TBW numbers appeared to alternate with CEW, i.e. TBW peak captures occurred during low CEW numbers; in North Carolina TBW captures occurred directly in phase with those of CEW. This phase shift between the two species manifested itself in the continuous presence of Heliothis spp. larvae in cotton throughout July and August in Arkansas.

The critical or "alarm" points in the trap catches for each year, which indicated impending oviposition during the pilot test, are shown in Figs. 1, 2 and 3. Egg counts shown are an average of all fields sampled. In June and July of all three years, pheromone trap catches of CEW began to increase one to two days before increases of eggs sampled in the field and continued to increase as egg counts became higher. In August, when populations became large, an increase in catch warned of potential oviposition; however, variations in later trap catches became difficult to interpret because of decreased trap efficiency. A simulation model of the pheromone trap (Hartstack et al. 1976a) has projected that this behavior is caused by competition from large numbers of female moths for the males.

Patterns of CEW trap catch varied in the two years (1981 and 1982) at Portland, AR. In 1981, numbers caught peaked at ca. 40 moths/trap-night in April, June, and July, indicating little increase between generations (Fig. 1B). In 1982, CEW trap catch (Fig. 2B) varied from a peak of 22 in March to peaks of 15.5, 10.9, 59.4, and 114.0 moths/trap-night in April, May, June and July, respectively. CEW moths were caught much earlier in 1982 than in 1981 with the first moth being caught on March 14 in 1982 compared to March 29 in 1981. The first major peak in 1982 occurred on March 21 compared to April 15 in 1981.

Oviposition occurred in Arkansas earlier in 1982 than in 1981 with peaks ca. 7-10 days sooner in June and July. Egg counts (Figs. 1B and 2B) indicate that Heliothis spp. numbers were much higher the second year. Peaks in egg numbers in 1981 were 608; 3,089; and 23,126 eggs/ha, in June, July, and August, respectively. In 1982, egg count peaks varied from 1,927 in June to 11,816 and 58,600 eggs/ha, respectively, in July and August. Also, in 1982 there was increased use of insecticides: 63 total applications to test fields in 1981 vs. 120 total applications in 1982 (see Lopez and Morrison, this monograph).

Peak CEW trap catches in North Carolina, for comparison, were 93, 99, and 161 moths/trap-night on May 23, July 7, and August 9, respectively. First catch occurred on April 20, 1983. Egg peaks in 1983 were 5,248 eggs/ha on June 30 and 42,061 eggs/ha on August 9. Egg numbers began to rise again in late August, the first signs of a fourth generation. This generation, predicted to peak in September, was not completely sampled and was not included in the figures.

The first TBW moth was caught on April 7, 1981 and on April 2, 1982 in Arkansas, and on April 29, 1983 in North Carolina. The first major peaks occurred on May 3, 1981 and May 7, 1982 in Arkansas, and May 28, 1983 in North Carolina. Again, timing was delayed in North Carolina compared to Arkansas as noted with CEW.

MOTHZV Predictions. In Arkansas during 1981, the model, with initialization data through May 12, predicted Heliothis oviposition June 1-26 with peaks on June 7 of 5,446 eggs/ha and on June 21 of 4,767 eggs/ha (Fig. 4A). Eggs were found in cotton June 8-29 with a peak of 608 eggs/ha on June 25. The model predicted third generation oviposition July 6-31 with a peak on July 10 of 27,329 eggs/ha and a broad peak July 20-28 of ca. 7,200 eggs/ha.

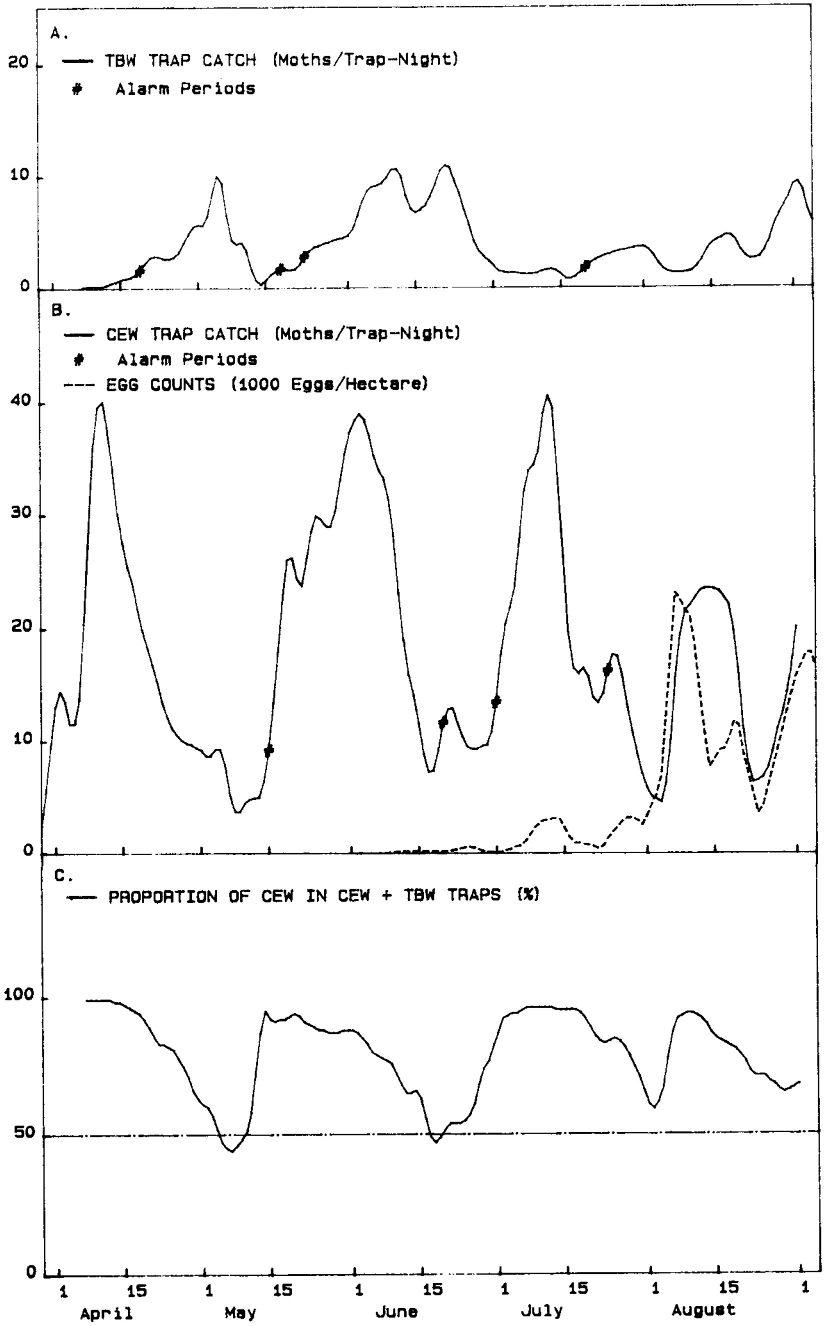

FIG. 1. Pheromone trap catches, Heliothis spp. egg counts, and proportion of CEW at Portland, AR, in 1981.

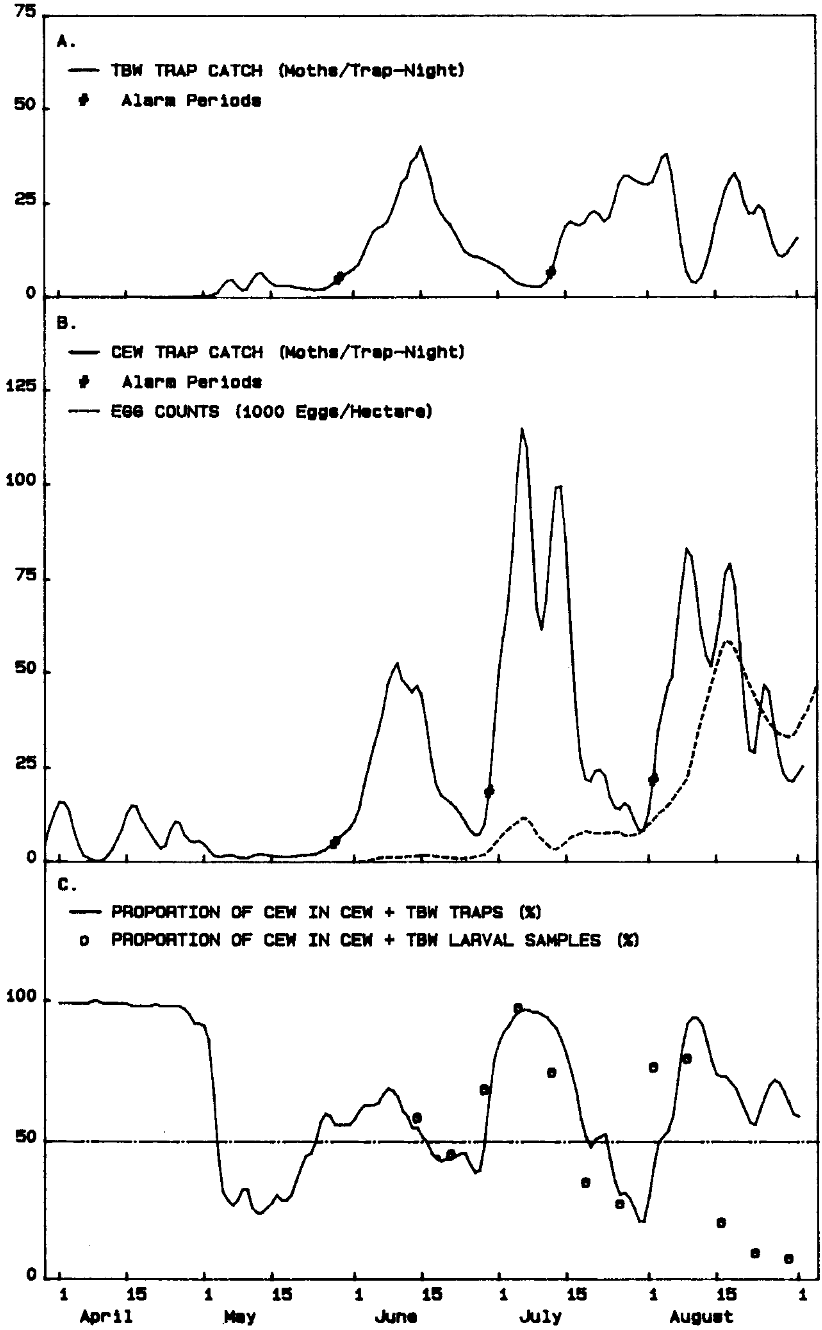

FIG. 2. Pheromone trap catches, Heliothis spp. egg counts, and proportion of CEW at Portland, AR, in 1982.

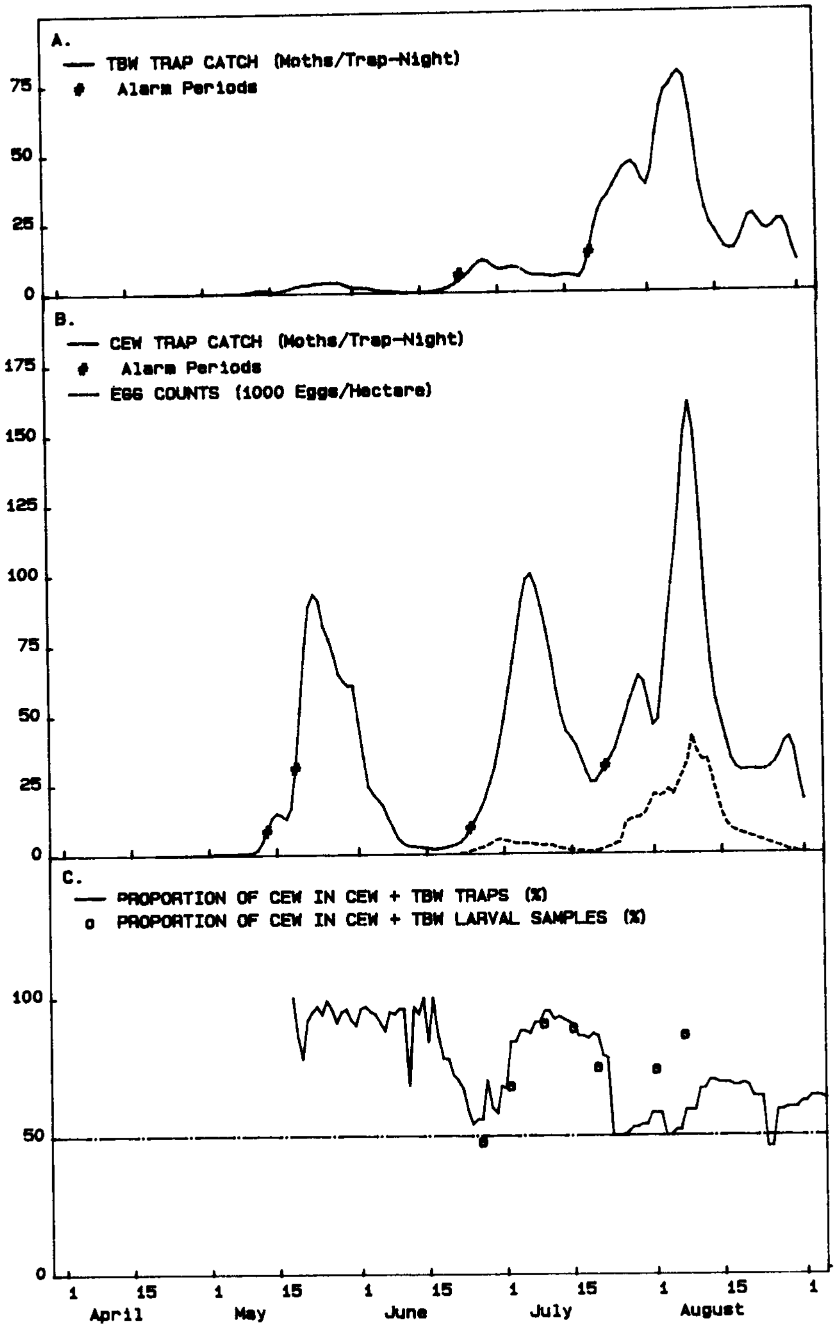

FIG. 3. Pheromone trap catches, Heliothis spp. egg counts, and proportion of CEW at Kitty Fork, NC, in 1983.

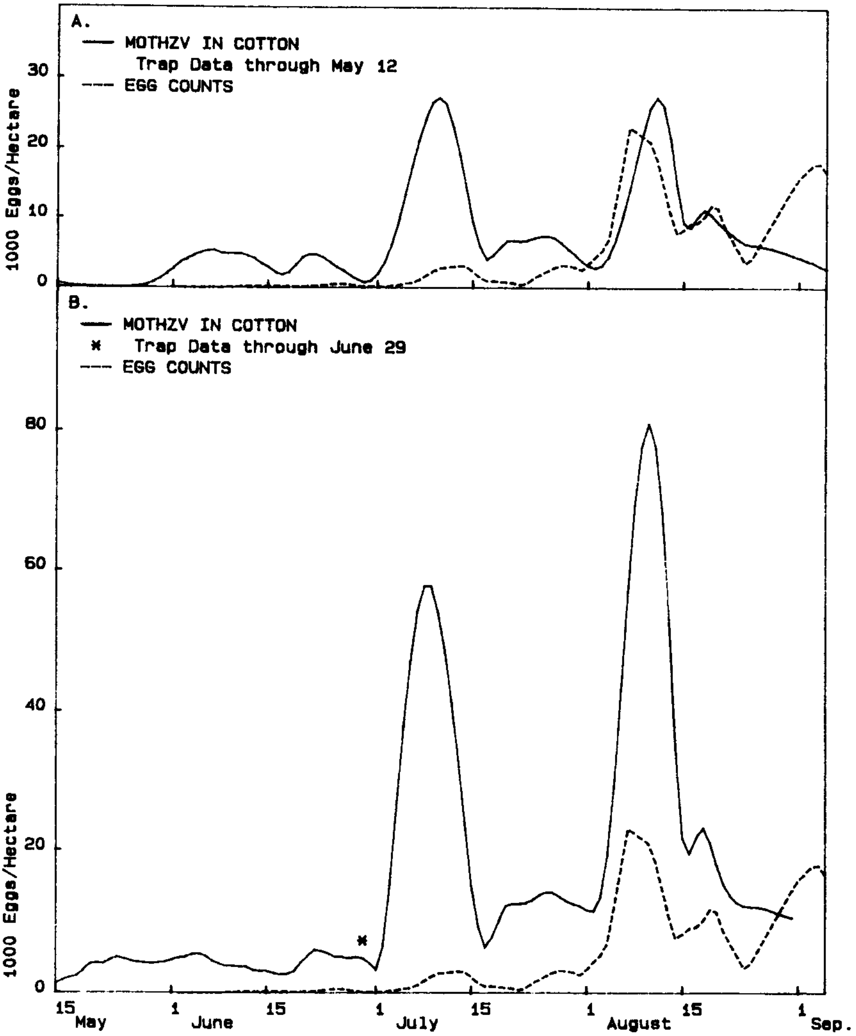

FIG. 4. Prediction of eggs in cotton by MOTHZV model on (A) May 12, and (B) June 29, compared to egg counts of Heliothis spp. at Portland, AR, in 1981.

Actual egg counts showed continuous oviposition throughout July with a peak of 3,089 eggs/ha on July 13. Predicted peaks were four days early for both June and July. The fourth generation peak was predicted for August 11, four days later than indicated in the egg counts.

The June 29, 1981 update (Fig. 4B) predicted third generation oviposition July 4-13 with a peak of 57,744 eggs/ha on July 8 which was five days before the sampled egg peak. Also predicted was an ovipositional period August 6-14 with a peak on August 10 of 81,097 eggs/ha. This compared to a sampled egg peak of 23,126 eggs/ha on August 7, three days earlier. A broad peak was observed in test fields August 5-11 with a peak that was not well defined.

In Arkansas during 1982,. a prediction was made on May 27 (Fig. 5A). Numbers predicted were lower than in 1981 because early season trap catch peaks were lower. Oviposition was predicted June 12-29, July 15-28 and August 13-27 with peaks of 4,067; 16,872 and 25,747 eggs/ha on June 22, July 18 and August 22, respectively. Egg counts indicated that oviposition occurred June 7-21 with a peak on June 15 of 1,927 eggs/ha; July 2-28 with a peak on July 6 of 11,816 eggs/ha and an extended period July 19-26 of ca. 8,200 eggs/ha; and August 6-26 with a peak on August 17 of 58,600 eggs/ha. The model closely predicted third generation timing in late July, but was five to seven days late on June and August peaks, although the complete ovipositional periods matched closely. The early July peak detected in the field was not predicted by the model, suggesting that these eggs resulted from moths which did not emerge locally (Hartstack et al. 1982, Mueller and Phillips 1983).

The model was updated on June 21 (Fig. 5B) with oviposition predicted July 9-26 and August 13-28 with peaks of 41,769 and 64,878 eggs/ha on July 15 and August 20, respectively. Higher trap catches in June 1982 (Fig. 2) than June 1981, despite lower catches in March-May resulted in increased number of eggs predicted. Prediction of the third generation covers late July egg counts timewise, although initiation is predicted three days earlier than the May 27 prediction. The early July peak seen in the field is missed, as it was in the May 27 prediction. The predicted August peak occurred three days after the sampled egg peak, which was two days closer than the May 27 prediction.

Another update was made for Arkansas on July 23, 1982 (Fig. 5C). A major ovipositional period was predicted for August 6-23 with peaks of 87,534 and 82,703 eggs/ha on August 10 and 17, respectively. Initiation of the August peak seen in the field was simulated closely. The big shift in timing for this August prediction was a result of including early July trap catch in the insect numbers used to initialize the model, numbers which were not predicted as progeny of earlier trap catches. The timing of the second peak in the fourth generation egg prediction for August matches exactly with the timing of the peak seen in the field.

The prediction results for North Carolina in 1983, shown in Figs. 6 and 7, were computed with actual temperature data included through August 6 in order that temperature prediction not enter the consideration of timing. The model was first run on June 16 (Fig. 6A). Oviposition was predicted July 2-22 with a peak of 60,934 eggs/ha on July 12 for second generation and August 6-31 with a peak of 126,143 eggs/ha on August 16 for the third. Egg samples indicated oviposition during the period of June 23 to July 17, peaking at 5,248 eggs/ha on June 30 and another from July 22 to August 27, peaking at 42,061 eggs/ha on August 9. Model predictions of oviposition were late, running 7-12 days behind field data. As in 1982, an early July peak occurred which was not predicted from early season pheromone trap catches. Weather was cool enough in North Carolina so that the July population represents only the second generation.

The model was run again for North Carolina on July 21, 1983 (Fig. 6B). Inclusion of late June trap catch in the initialization data resulted in calculation of a corresponding oviposition during that period. The timing

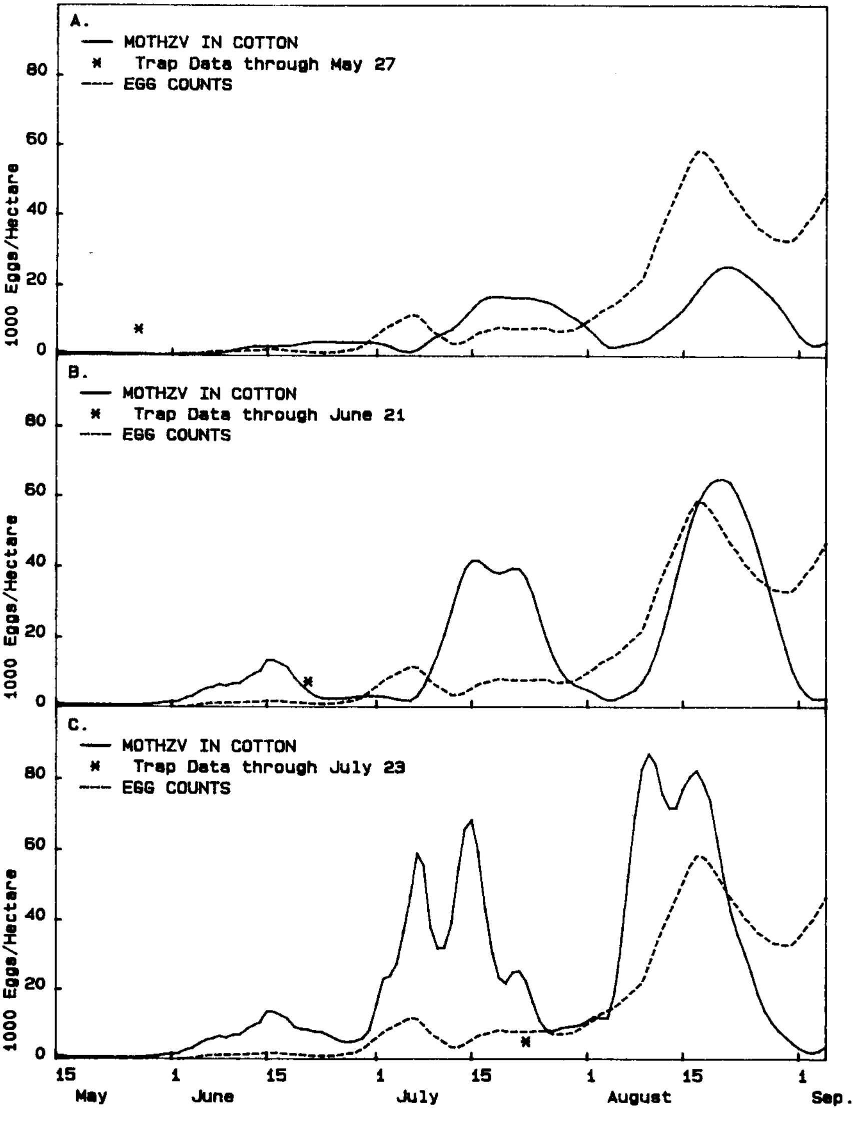

FIG. 5. Prediction of eggs in cotton by MOTHZV model on (A) May 27, (B) June 21, and (C) July 23, compared to egg counts of Heliothis spp. at Portland, AR, in 1982.

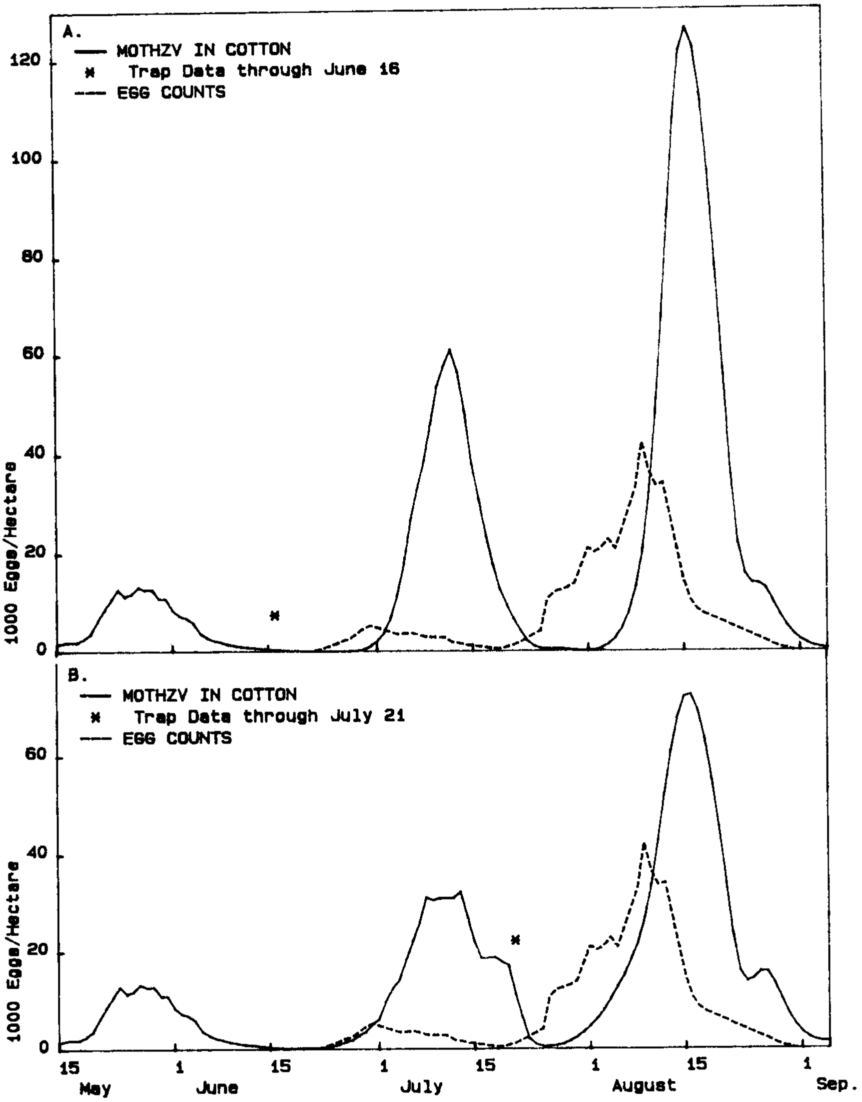

FIG. 6. Prediction of eggs in cotton by MOTHZV model on (A) June 16, and (B) July 21, compared to egg counts of Heliothis spp. at Kitty Fork, NC, in 1983.

of the predicted third generation peak in August was unchanged from the June 16 simulation, although the complete ovipositional period was predicted to begin five days sooner. The agreement between this prediction and the one made for August on June 16 indicates that the predicted oviposition is predominantly the result of progeny of the population sampled by early season trap catch, so any adult movement before July 21 was low in numbers.

Potential Movement of Moths. Hartstack et al. (1982) reported circumstantial evidence that a major migration of CEW moths into the Portland, AR, area occurred in the spring of 1981. Their findings were based on comparison of pheromone trap catches in Texas and Arkansas and emergence of CEW moths from diapause at College Station, TX. CEW moths were caught at College Station 42 days, and at Portland 14 days, before the first CEW moth emerged from diapause at College Station. Peak trap catches of 110 and 44 moths/trap-night occurred at College Station and Portland, respectively, four days before the first moth was collected in field emergence cages at College Station.

In March and April there is a large area of corn in varying stages of growth in northern Mexico that could produce large numbers of CEW moths (J. Lopez, personal communication). Hartstack et al. (1982) showed that atmospheric opportunities for transport of CEW moths from Mexico to Texas and Arkansas prevailed often during the early season of 1981. Similar conditions occur each year (Muller 1977).

The potential for TBW migration into Arkansas would seem to be similar to CEW. However, the timing of pheromone trap catches followed diapause emergence timing closely at College Station; so Hartstack et al. (1982) assumed that little early season migration of TBW occurred, unless it took place at the same time as diapause emergence. Whether there are behavioral differences or, simply, the adult populations of TBW moths available for transport are more limited than for CEW at that time of year needs to be determined in future research.

In addition to pheromone trap catches following the emergence of TBW from diapause, Lopez et al. (1984) reports that TBW moths emerge from diapause ca. nine days before CEW moths. Applying these results to the Arkansas area, estimates of CEW diapause emergence timing can be made by comparison with TBW trap catch timing.

The first significant peak in TBW moth catch for each year in Arkansas occurred on May 5, 1981 and May 7, 1982. Based on these dates, estimated peak CEW emergence would have occurred on May 14, 1981 and May 16, 1982. These estimates are compatible with data reported by Stadelbacher and Pfrimmer (1972) who found that CEW emergence from diapause peaked May 15-25 in 1967, 1968, and 1970 at Stoneville, MS, which is located across the Mississippi River from Portland.

The first TBW moth catch for each year occurred on April 7, 1981 and April 1, 1982, placing the estimated date of CEW emergence in Arkansas on April 16, 1981 and April 10, 1982, respectively. The former date is 14 days later than the first observed CEW peak moth trap catch in 1981 (14 moths/trap-night on April 2) while the latter is 21 days later than the first peak in 1982 (24 moths/trap-night on March 20). Thus, CEW catches were already peaking before the time that emergence was calculated to begin, indicating that an early immigration of CEW occurred both years in Arkansas.

The cropping pattern in North Carolina is different from that of Arkansas. Suitable alternate hosts such as corn and tobacco are generally grown near cotton in North Carolina. Corn is especially important because it is highly attractive to CEW, particularly when silking. Larvae develop somewhat faster on corn than in other crops and large numbers of adults can emerge from the generation of larvae that are reared on corn ears. Tobacco is an attractive host to TBW and may play an important role in the population dynamics of that species. TBW were not investigated further because their numbers, as indicated by trap catches, were relative small compared to CEW and tobacco is not included in the MOTHZV model.

To check the possible effect of an alternate host on the timing of oviposition in cotton, a simulation run was made, beginning with CEW in corn (Fig. 7A). The model was initialized with trap data through the first generation, June 16. The predicted occurrence of the second generation varied little from the prediction for cotton (Fig. 6A), although it was indicated as finishing four days sooner. Predicted second generation moths from corn were then used to initialize the model in a successive simulation for cotton, resulting in the third generation prediction shown in Fig. 7A. Peak timing was two days from the peak recorded in North Carolina field data.

The simulation in corn in North Carolina suggests that the third generation egg peak in August is probably the result of moths moving from corn into cotton. However, egg counts in late July were still not predicted by this simulation run. As in Arkansas, this may indicate that these eggs were laid by moths moving into cotton from other areas.

To study the potential source of insects in North Carolina, another simulation was made using trap catches (S. Roach, unpublished data) and temperature in Florence, SC, located ca. 150 km southwest of the Kitty Fork, NC, test area. The predicted timing of oviposition for Florence (Fig. 7B) was one wk earlier than that in the simulation for Kitty Fork (Fig. 7A). Extrapolating this result, eggs found in the two wk period of late July and early August potentially could have been oviposited by moths that emerged from corn located southwest of the test site at distances up to ca. 300 km.

Two frontal passages occurred during the late July to early August time period in North Carolina: one on July 25 with southwesterly air flow July 23-25, and a second on August 3 with southwesterly flow from July 31 to August 6. Therefore, conditions were present to support movement of insects during the period in question. The dates of the two fronts correspond closely to days in which sharp increases were found in egg counts (Fig. 7A).

It appears that movement may play an important part in determining the population dynamics of Heliothis. The evidence suggests that CEW moths caught in Arkansas in March and April both years were not from local emergence. Results from the MOTHZV model also suggest that moths moved into the Arkansas test site in early July of 1982 and into the North Carolina test site in late June and late July in 1983. These later moths, in June and July, would not have necessarily come from long distances; they may have moved moderate distances from one host to another.

CONCLUSIONS

Pheromone baited traps are useful tools for monitoring adult populations of CEW and TBW moths. Although absolute numbers cannot be determined from trap catches, trends between months, species, areas and years can be of great value in studying the population dynamics of these pests. With proper attention, traps can give one to two day warning of incipient oviposition. Pheromone trap catches can thereby serve as an alert for scheduling of field scouting to ascertain pest numbers and aid in making control decisions. Additional research is needed to understand the biological and environmental factors that affect pheromone traps so that trap catches can be related to actual moth numbers.

Pheromone trap catches were used as input to the Heliothis population dynamics model, MOTHZV. Success with MOTHZV was variable. Predictions in 1981 were much closer to observed field data than in succeeding years. Errors in 1981 were on the early or safe side for use in scheduling scouting. Predictions for the next two years appeared to be confounded by the influx of moths, out of cycle with locally produced moths. There is strong evi-

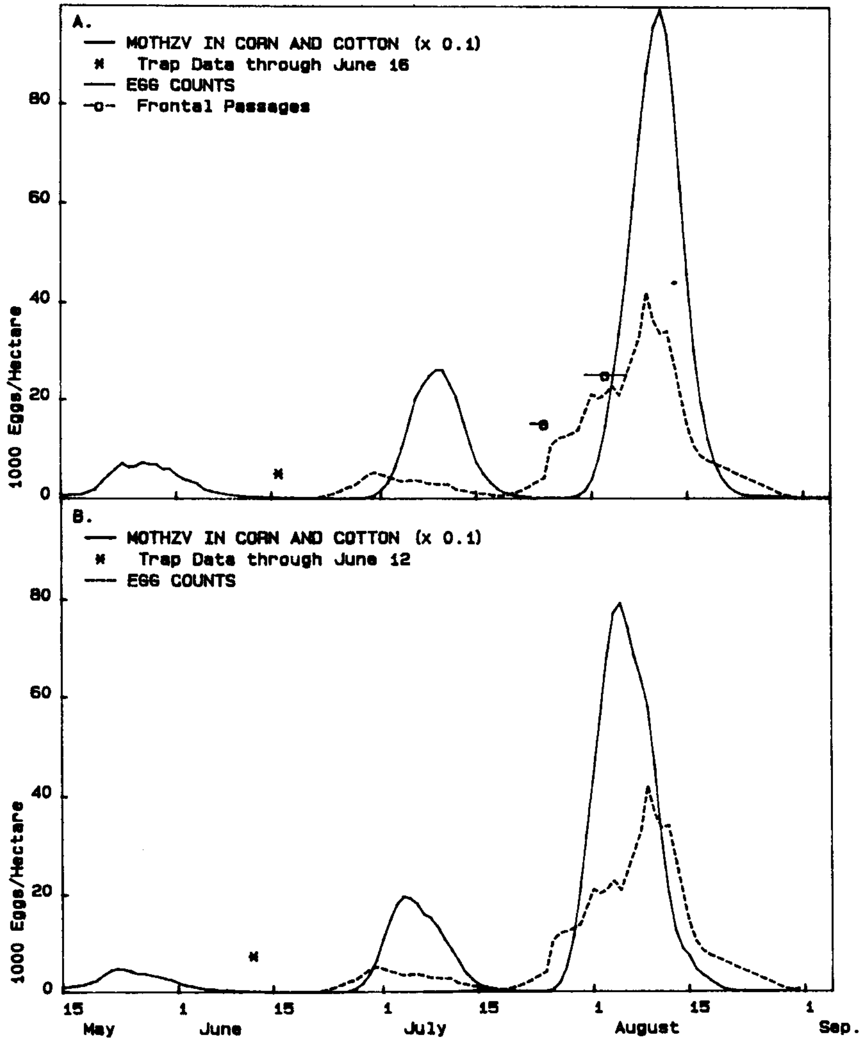

FIG. 7. Prediction of eggs by MOTHZV model in corn at (A) Kitty Fork, NC, on June 16, and (B) Florence, SC, on June 12, followed by cotton at Kitty Fork, NC, compared to egg counts of *Heliothis* spp. at Kitty Fork, NC, in 1983.

dence of long-range migration of CEW moths in early spring and simulation results indicate that in-season movement of CEW, and possibly TBW, may be taking place.

Application of MOTHZV to date has been primarily for predicting ovipositional timing; simulation results of population size have never been consistent. Improvement in the quantitative description of pertinent biological components included in models such as MOTHZV, e.g. mortality and fecundity, is not possible without a clear definition of the population being studied. It appears that insect movement will need to be a primary consideration in future studies of *Heliothis* population dynamics. The timing and the number of insects involved in movement need to be understood before significant improvement can be made in the precision or accuracy of *Heliothis* population predictions.

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