HELIOTHIS SPP.\(^1/\) AND SELECTED NATURAL ENEMY POPULATIONS
IN COTTON: A COMPARISON OF THREE INSECT CONTROL
PROGRAMS IN ARKANSAS (1981-82) AND NORTH CAROLINA (1983)

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ABSTRACT

The egg parasite, Trichogramma pretiosum (Riley), was tested in
augmentative releases in Arkansas (1981-82) and North Carolina (1983) for
management of the bollworm, Heliothis zea (Boddie), and tobacco budworm, H.
virescens (F.), in cotton. There were no differences in yield between
fields treated by release of T. pretiosum, insecticides, or inaction
(check) in 1981. In 1982, Trichogramma release was abandoned, but insec-
ticial control fields yielded 18% more lint cotton than did check fields.
In 1983, cotton fields in North Carolina treated by seven augmentative
releases of T. pretiosum at 306,000 emerged adults/ha/release yielded
significantly (P<0.15) more cotton than fields where the parasite was not
released, i.e., inaction or check fields. However, bollworm and tobacco
budworm populations exceeded established economic thresholds despite rela-
tively high levels of egg parasitism (40 to 60%) and predator populations
(30,000 to 60,000/ha). Consequently, insecticidal control fields yielded
more cotton than did check or T. pretiosum release fields. We conclude
that it is not presently feasible to manage Heliothis spp. in cotton by
augmentative releases of T. pretiosum.

Predator populations were generally higher in T. pretiosum and check
fields than in insecticidal control fields. Moreover, predator populations
were greater in North Carolina than in Arkansas. Of 5,410 bollworm and
tobacco budworm larvae collected, 30.9, 50.1, and 34.5% were parasitized
during 1981, 1982, and 1983, respectively. Microplitis croceipes (Cresson)
was the predominant parasite each year.

INTRODUCTION

Ridgway and Lingren (1972) reviewed the role of predators and para-
sites in regulating populations of bollworm (BW), Heliothis zea (Boddie),
and tobacco budworm (TBW), H. virescens (F.), emphasizing studies conducted
in the southern USA. They concluded that predator genera such as Geocoris,
Nabis, Orius, Hippodamia, Coleomegilla, and Chrysopa were of major importance.

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ducts or vendors that may also be suitable.
in suppressing BW/TBW populations. These authors also stated that the most important parasites in the southern region probably did not exceed 10 or 15 species. Numerous researchers have reported that where predator and parasite populations were reduced by use of synthetic organic insecticides in cotton, BW/TBW became a pest (Newsom and Smith 1949, Wille 1951, Whitcomb and Bell 1964, van den Bosch et al. 1969, and Ridgway et al. 1967). Newsom and Brazzel (1968) articulated the concept of conserving natural enemies by avoiding use of insecticides during early season, but did acknowledge situations where control of early-season pests, e.g., plant bugs, might become mandatory. In this event, they suggested the use of highly selective insecticides, at the minimum effective dosage, for their control.

We report here on the occurrence of BW/TBW and selected natural enemy populations in cotton where three approaches to BW/TBW control were employed: (1) releases of Trichogramma pretiosum (Riley) to augment other factors suppressing BW/TBW populations; (2) application of insecticides; and (3) inaction (checks), which utilized no tactics for intervening in BW/TBW population increase. The occurrence of boll weevil, Anthonomus grandis (Bohemian), is also reported since it was often a serious pest in test fields. Production and release of T. pretiosum are reported by Morrison and Bouse (this monograph) while Lopez and Morrison (this monograph) discuss in detail egg parasitism by released T. pretiosum. Prediction of BW/TBW populations based on pheromone trap catches of moths is reported by Witz et al. (this monograph) so, we report only the occurrence of moths as they relate to egg and larval occurrence in the cotton fields. Other areas reported in this paper include plant fruiting and pest damage, insecticide usage, yield and net revenue of insect control costs as a measure of program effectiveness.

METHODS

Cotton fields in southeast Arkansas near Portland (1981, 1982) and southern North Carolina near Clinton (1983) were sampled as part of a pilot test to evaluate the feasibility of managing BW/TBW in cotton by augmentative releases of T. pretiosum. Comparison of this augmentative approach to alternative programs was desired; thus three programs for BW/TBW control were established: (1) releases of T. pretiosum; (2) insecticidal control; and (3) inaction (checks). In 1982, releases of T. pretiosum were discontinued after release fields were repeatedly treated for BW/TBW larval infestations. Thus, fields originally designated for T. pretiosum releases were considered as insecticidal control fields and the pooled data were compared to that from check fields where BW/TBW populations received no insecticide applications. Some characteristics of fields sampled each yr are summarized in Table 1.

Moth Monitoring. In 1981 and 1982, forty 75-50 cone pheromone traps (Hartstack et al. 1979) were installed in a ca. 500 km² area around Portland, AR to monitor moth occurrence prior to and during periods when BW/TBW eggs and larvae were sampled. See Witz (this monograph) for prediction of oviposition periods. In 1983, 20 traps were installed adjacent to cotton fields near Clinton, NC. Half the traps each year were baited with BW pheromone and the remaining traps were baited with the TBW pheromone. The baits used in the traps were the 4- and 7-component pheromones identified by Klun et al. (1979) for BW and TBW, respectively. The pheromone was laminated between layers of plastic (Hercon Div., Health-Chem Corp., New York, NY) at the rates of 0.4 and 6.4 mg/cm², respectively. The traps were installed on March 18 in 1981, March 1, in 1982, and April 20 in 1983, and were located along accessible field margins, roadways, and fence lines near the test fields. The traps were serviced ca. three times/wk in 1981,
daily in 1982 except for a few weekends, and daily beginning May 3 (date first moths captured) and three times/wk after June 6 in 1983. The traps were rebaited every two wks. Day to day variation in trap catches was smoothed by using a 3-day running average.


<table>
<thead>
<tr>
<th>Program</th>
<th>No. fields</th>
<th>Field size (ha) x ± SD</th>
<th>No. insecticide applications x ± SD</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>Heliotris</td>
</tr>
<tr>
<td>Trichogramma release</td>
<td>6</td>
<td>27 ± 5.8</td>
<td>4.5 ± 1.4</td>
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<tr>
<td>Insecticidal control</td>
<td>6</td>
<td>34 ± 5.1</td>
<td>6.7 ± 1.6</td>
</tr>
<tr>
<td>Check</td>
<td>8</td>
<td>6 ± 2.3</td>
<td>4.4 ± 1.9</td>
</tr>
</tbody>
</table>

1982

| Insecticidal control | 17       | 28 ± 7.7               | 6.9 ± 2.1                           |
| Check               | 4        | 8 ± 0.0                | 2.0 ± 1.4 a/                        |

1983

| Trichogramma release | 8        | 5 ± 3.7                | 4.8 ± 0.7 b/                        |
| Insecticidal control | 8        | 12 ± 8.5               | 8.3 ± 0.5 b/                        |
| Check               | 4        | 3 ± 1.9                | 4.5 ± 0.6 b/                        |

a/ All insecticides applied to check fields were made prior to July 1 for control of boll weevil or plant bugs.
b/ Includes two early-season (June 20, 27) insecticide applications for control of overwintered boll weevils. All fields received an additional 6-9 applications for control of diapausing weevils after August 22 as part of the U.S. Dept. Agric. Boll Weevil Eradication Program.

Whole Plant Examination. Whole plant examinations were conducted to assess numbers of cotton fruiting forms, pest insects (BW/TBW eggs and larvae and boll weevil adults), and their damage. Each field was considered as one replication within a program and was sampled twice/wk in 1981 and 1982. Four subsamples (subsample unit = 2.1 row-m) were taken/sample date and actual counts were converted to numbers/ha. A non-parametric statistical method based on taking ranks of the converted values and conducting a one-way analysis of variance of these ranks was performed to address potential non-normality of data (Quade 1966). Variable means were compared using a test for least significant difference at P=0.05.

In 1983, programs were blocked by location with each field considered as a replication and sampling conducted once/wk. Individual fields were divided into 12 strata with one subsample (unit = 1.0 row-m) taken/stratum. Actual counts were converted to numbers/ha. Converted values were ranked within blocks and an analysis of variance was performed on these ranks (Conover 1980). Variable means were compared using a test for least significant difference at P=0.05.
Drop Cloth and D-Vac® Sampling. Predator populations were sampled with drop cloth in Arkansas in 1981 and 1982, and use of D-vac in North Carolina in 1983. Dimensions for the drop cloth were 0.9m x 1m and sampling was conducted once/wk at four locations/field. The procedure consisted of spreading the cloth on the ground between two rows, and shaking the plants in 0.9 row/m on both rows over the cloth. D-Vac sampling devices were equipped with a 25-cm cone. Samples were taken once/wk on three row/m at four locations/field. Predators recorded from drop cloths based on visual sighting were Geocoris spp., Orius spp., spiders, lacewings (chrysopids and hemerobiids), coccinellids, and nabids. These same predators were recorded from D-vac samples based on stereoscopic examination of specimens returned to the laboratory. Actual counts from drop cloth and D-vac samples were converted to numbers/ha. Analyses of data and testing for significant differences were performed as described for data from whole plant examinations.

Larval Parasitism. Larvae were collected to determine BW:TBW ratio, which parasitic insects attacked these larvae, and the percentage of larvae parasitized. Larvae were collected weekly from each field. Observers walking between rows detected larval presence based on feeding signs. Larvae were then collected by hand from terminals, flower buds, flowers, and bolls in all portions of the cotton plants and transported to a field laboratory. Each larva was isolated on soybean flour-wheat germ diet (King and Hartley 1985) in 22.5 ml plastic cups and confined with a wax-impregnated cardboard lid. Host larvae were identified to species using criteria described by Brazzel et al. (1953). Larvae were checked daily to ascertain the fate of each. Fates were categorized as: (1) larva completed development to the pupal stage and was not parasitized; (2) larva was parasitized as evidenced by emergence of a parasitic insect larva; (3) larva escaped by chewing a hole in the cardboard lid and crawling out; (4) larva was diseased based on symptoms; or (5) larva died due to undetermined causes. Percentage parasitization was calculated by dividing the number of parasitized larvae by the total number of larvae completing development plus parasitized and escaped larvae. Due to the large size of escaped larvae and their apparent mobility, we assumed them to be healthy and not parasitized. Diseased insects were not included in calculations though they could have been parasitized and the pathogen precluded parasite development (e.g., King and Bell 1978). Parasites emerging from host larvae were identified to species using reference collections.

Yield and Insect Control Costs. Lint yield (kg/ha) for each test field in 1981 and 1982 is based on hand-picked samples (10 x 3.1 row/m). Gin tickets for each test field in 1983 were reviewed to determine lint yield. Insect control costs for each field are based on information supplied by individual growers and commercial aerial applicators.

TESTS AND RESULTS

Moth Monitoring. BW moths were caught before TBW moths in Arkansas and BW moths occurred earlier in 1982 (March 14) than in 1981 (March 29). In 1981, the BW trap catch peaked at ca. 40 males/trap/night in April, June, July, and September (Fig. 1). In 1982, the BW trap catch went from a peak of 22 in March to a peak of 16, 11, 59, and 120 males/trap/night in April, May, June and July, respectively (Fig. 1). The first TBW moth caught in 1981 was on April 7 and on April 2 in 1982.

In North Carolina (1983), the first BW and TBW moths caught were on April 20 and April 29, respectively. The number of BW moths emerging from diapause peaked ca. May 25 and oviposition was observed primarily in whorl corn and tobacco, though uncultivated hosts and vegetable crops were also
infested. As seen in Fig. 1, TBW moth catches remained relatively low (< 10 males/trap/night) until late July when captures greatly increased.

Whole Plant Examination. Increases in BW/TBW egg populations occurred on about the same dates each of the two yrs in Arkansas (Fig. 2). Linear regression analysis revealed no correlation between moth captures and Heliotis spp. egg densities ($r^2 = 0.09$).

Oviposition periods observed in cotton were relatively distinct in 1981. During June, egg densities across programs averaged less than 200/ha, but progressively increased in July (1,571 eggs/ha) and August (10,361 egg/ha). Significantly higher egg populations were observed the wks of August 27 and September 3 in insecticidal control fields (Fig. 2). Oviposition periods were less defined in 1982 than in 1981 and egg populations were higher and more sustained in duration of occurrence (Fig. 2) than in 1981. During June, July, August, and September, 1982, egg populations across programs averaged 899, 6,928, 34,039, and 47,275 eggs/ha, respectively. Asynchrony of BW and TBW populations (as indicated by pheromone trap captures) resulted in sustained oviposition throughout the month of July. Egg densities in insecticidal control fields were significantly higher than those in check fields during the 3-wk period of July 29 to August 19.

Larvae establishing from eggs deposited the first two wks in July, 1981 in Arkansas numbered 3976, 4887, and 8632/ha in check, Trichogramma release, and insecticidal control fields, respectively, during the wk of July 16 (Fig. 3). Chlordimeform + methomyl (0.14 + 0.14 kg/ha) was applied to all nonseed cotton fields and insecticidal control fields as part of the Portland Bollworm Management Community program. Heliotis nuclear polyhedrosis virus (NPV) (Elcar®) was applied to Trichogramma release fields at a rate of 0.14 kg + 1.12 kg Gustol®/ha (larval mortality due to viral infection was estimated at 23% based on larval collections from Trichogramma release fields). Check fields were not treated for BW/TBW populations. Larval densities in check fields were significantly higher only for the wks August 20 and 27 when there were 3.4 times more large larvae (>6 mm length) and 2.6 times more total larvae in check fields compared to insecticidal control and Trichogramma release fields.

In 1982, larval densities reflected the higher egg populations and seasonal means were 8,416 and 9,952 larvae/ha in insecticidal control and check fields, respectively (Fig. 3). Despite numerically higher larval numbers in check fields as compared to insecticidal control fields, significant differences in larval densities were seldom observed.

Aerially-applied spray applications of insecticides for control of BW/TBW larvae averaged 3.7 ± 1.4, and 5.3 ± 1.6 in 1981 and 1982, respectively, in insecticidal control fields. Chlordimeform and organophosphates were the materials most often used to control BW/TBW eggs and larvae in 1981, but synthetic pyrethroids were generally substituted for the organophosphates in 1982. After initiation of spray operations, larval populations still averaged more than 10,000/ha in insecticidal control fields for the duration of the 1982 cropping season.

Based on field collected BW/TBW larvae in Arkansas, BW comprised 85% of the collections in 1981, but only 56% in 1982 (Table 2). Moreover, during the wks July 28 to August 4 and August 25 to September 8, 1982, TBW larvae comprised 70 and 87%, respectively, of the BW/TBW larvae collected. The increase in proportion of TBW larvae reflected increased catches of TBW moths during these time periods, though BW moths continued to outnumber TBW moths in trap catches (Fig. 1).
Fig. 2. Seasonal occurrence of Heliothis spp. egg populations in Trichogramma release (--), check (---) and insecticidal control (— —) cotton fields near Portland, AR (1981, 1982) and Clinton, NC (1983).
TABLE 2. Percentage of Bollworm Comprising Total of *Heliothis* app. Larvae Collected in Cotton.

<table>
<thead>
<tr>
<th>Week</th>
<th>1981 (n)</th>
<th>%</th>
<th>1982 (n)</th>
<th>%</th>
<th>1983 (n)</th>
<th>%</th>
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<tr>
<td>June 16</td>
<td>(6)</td>
<td>17</td>
<td>(26)</td>
<td>62</td>
<td>-</td>
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<tr>
<td>23</td>
<td>- b/</td>
<td>(79)</td>
<td>46</td>
<td>-</td>
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<tr>
<td>30</td>
<td>(2)</td>
<td>0</td>
<td>(21)</td>
<td>52</td>
<td>(78)</td>
<td>47</td>
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<td>July 7</td>
<td>-</td>
<td>(196)</td>
<td>98</td>
<td>(294)</td>
<td>86</td>
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<tr>
<td>14</td>
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<td>28</td>
<td>(151)</td>
<td>81</td>
<td>(98)</td>
<td>30</td>
<td>(103)</td>
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<tr>
<td>Aug. 4</td>
<td>(241)</td>
<td>73</td>
<td>(232)</td>
<td>60</td>
<td>(177)</td>
<td>84</td>
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<tr>
<td>11</td>
<td>(173)</td>
<td>79</td>
<td>(307)</td>
<td>89</td>
<td>-</td>
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<tr>
<td>18</td>
<td>(173)</td>
<td>87</td>
<td>(132)</td>
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<tr>
<td>25</td>
<td>(18)</td>
<td>78</td>
<td>(187)</td>
<td>11</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Sept. 1</td>
<td>-</td>
<td>(34)</td>
<td>9</td>
<td>-</td>
<td></td>
<td></td>
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<td>(1091)</td>
<td>85</td>
<td>(1619)</td>
<td>56</td>
<td>(1703)</td>
<td>83</td>
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</table>

a/ Represents total number of larvae which were identified as either bollworm or tobacco budworm.
b/ Denotes wks when no larvae were collected.

Significant differences between programs for squares or bolls damaged by BW/TBW larvae were only evident for limited time periods in 1981 and 1982 (Figs. 4 and 5). Lack of differences was due, in part, to the high degree of variability between fields within programs. Furthermore, as indicated in Table 1, *Trichogramma* release fields in 1981 were treated with insecticides for BW/TBW as well as boll weevil populations (primarily during August and September) and no statistical differences in BW/TBW damaged bolls/ha were evident between *Trichogramma* release and insecticidal control fields. In 1982, check fields had significantly higher BW/TBW damaged bolls/ha during the fourth wk of July and third wk of August compared to insecticidal control fields.

Boll weevil populations in Arkansas caused considerable damage to squares and bolls. Counts of squares and bolls damaged by this pest have been combined and are presented as damaged fruit (Fig. 6). In 1981, no early season insecticide applications were made for boll weevil and there was a progressive increase in damage until mid-July when the first applications were initiated. The majority of all test fields had received insecticide applications for boll weevil control by early-August and thereafter there was a decline in boll weevil damaged fruit. The need for frequent applications for control of this pest was the decisive factor in terminating *Trichogramma* releases in mid-August. In 1982, monitoring of boll weevil pheromone traps placed around the margins of all test fields indicated that numbers of emerging, overwintered weevils peaked at 8.8/trap during the wk of May 8. Thus, a decision was made to treat all cotton fields within the Portland community beginning June 9 with 0.28 kg/ha of azinphosmethyl. Additionally, test fields received three applications of diflubenzuron (0.07 kg/ha) at 5-day intervals and a final application of azinphosmethyl during the last wk in June (11 test fields did not receive the final azinphosmethyl application). These early season measures were
taken in an attempt to delay the build-up of boll weevil populations until August and eliminate the use of insecticides for boll weevil control during BW/TBW oviposition periods in July. As seen in Fig. 6, boll weevil damaged fruit in 1982 was low in all test fields until the end of August when high boll weevil populations developed.

Seasonal occurrence of BW/TBW egg populations in cotton fields near Clinton, NC (1983) are shown in Fig. 2. Moth trap captures (Fig. 1) and observations made in silking corn around June 25 indicated high numbers of BW were ovipositing in this crop. Ovpositional preference for corn was expected at this time (Johnson et al. 1975) and egg populations in cotton were very low, averaging ca. 1200/ha for the period June 29 to July 13. Despite these low egg densities during this period, larval populations (Fig. 3) attained treatment thresholds ("three live worms/100 terminals, squares, or bolls or 5% squares or young bolls damaged, plus presence of live worms", York 1983) the wk of July 13. At this time 82% of the larvae collected from cotton were categorized as first to third instar.

Chlordimeform + permethrin (0.14 + 0.11 kg/ha) was applied with a high clearance sprayer to all insecticidal control fields and larval densities were significantly reduced compared to numbers observed in check and Trichogramma release fields. (Fields designated for parasite releases had not yet received T. pretiosum releases.) By July 20, larval populations had peaked in these fields left untreated with insecticides and no differences in larvae/ha between programs were evident by July 27.

Both BW and TBW moth captures began to increase around July 22 (Fig. 1) and egg number increases in cotton were detected on July 25. Significantly higher egg densities were observed in Trichogramma release and check fields compared to insecticidal control fields the second and third wks of August.

Larvae hatching from eggs oviposited around July 25 reached treatment thresholds in insecticidal control fields and spray treatments (chloridimeform + permethrin) were initiated on August 1. Additionally, two more applications to all insecticidal control fields were made for control of this F3 generation larval population. Azinphosmethyln (for boll weevil) was also added (after August 1) to the spray mixture for BW/TBW larvae control. No insecticidal control fields required BW/TBW treatments after August 10 except for one late maturing field.

Trichogramma pretiosum was aerially broadcast in all release fields July 26 and releases continued at 2-3 day intervals for a total of seven applications/field. No releases were made after August 10 since boll weevil treatments were initiated in all Trichogramma release fields (as well as check fields) on August 12 as part of the USDA Boll Weevil Eradication Program.

No significant difference in larval numbers/ha between Trichogramma release (7892/ha) and check (7297/ha) fields for the wk of August 10 was observed though both had significantly higher populations than insecticidal control fields (615/ha). All Trichogramma release and check fields were treated for threshold levels of boll weevils and BW/TBW on August 12 with an ethyl-methyl parathion (0.84 + 0.42 kg/ha) and azinphosmethyln (0.28 kg/ha) mixture. Five of the eight Trichogramma release fields and two of the four check fields required an additional application for BW/TBW control on August 16.

Field collections of larvae in North Carolina revealed that 83% were BW (Table 2). A greater proportion of the larvae were expected to be TBW based on pheromone trap catches (Fig. 1), but tobacco was apparently relatively more attractive as a host.

Damage to fruit (squares and bolls) by BW/TBW larvae was significantly greater during mid-July of 1983 in Trichogramma release and check fields.
when compared to insecticidal control fields (Fig. 4 and 5). In actuality, Trichogramma release fields were check fields also, since parasite releases were not initiated on the sustained low egg densities during June 29 to July 13. After releases were initiated on July 26, fruit damage by BW/TBW larvae in Trichogramma release fields was not significantly different than that in check fields, yet square damage (2-wk period) and boll damage (4-wk period) in these two programs were significantly higher than that observed in insecticidal control fields.

Considerable fruit damage by boll weevil (Fig. 6) occurred in Trichogramma release and check fields during August and was significantly higher than in insecticidal control fields. The seasonal occurrence of undamaged squares/ha (Fig. 7a) in 1983 revealed significantly higher numbers of squares in insecticidal control fields than in the other two programs during the wk of July 20. Undamaged bolls/ha (Fig. 7b) were also significantly higher in insecticidal control fields from the week of August 10 until the remainder of the cropping season.

Drop cloth and D-Vac samples. The combined populations of selected predator groups (Geocoris spp., Orius spp., spiders, lacewings, coccinellids and nabids) are presented in Fig. 8. Each predator group has been separately tabulated with weekly means given in Table 3 for each program each yr. Various spiders, Geocoris spp. [mainly C. punctipes (Say)] and coccinellids were the most numerous of all predators sampled by drop cloth in Arkansas, but predator populations in 1982 were about one-fourth as numerous as populations in 1981. In both years, early season predator populations were at similar levels; however, in 1982, after pin head square applications (June 10-30) of azinphosmethyl to test fields for overwintered boll weevil control, significantly lower predator populations were observed from July 22 until the end of the cropping season in insecticidal control fields (Table 3). In general, predator populations in 1981 were higher in check and Trichogramma release fields, though wks in which significant differences occurred were infrequent since applications for boll weevils were common in most test fields by early August.

Selected predator populations were monitored by D-Vac in North Carolina and the most numerous predator groups were Orius spp., Geocoris spp., and spiders. Predator numbers were at similar levels in the three programs (ca. 10,000/ha) during the initial BW/TBW oviposition period in cotton (June 29 to July 13) and increased to a mean of ca. 28,000/ha by July 20 in Trichogramma and check fields. Predators remained at this relatively stable population until late July. Populations of Geocoris spp. and Orius spp. averaged 8,380 and 12,115/ha, respectively, when BW/TBW egg populations began to increase in Trichogramma release fields during late July. On August 3, these same predator groups averaged 10,176 and 6,138/ha, and on August 10 averages were 15,144 and 27,965/ha (Table 3). Similar trends in predator populations were also observed in check fields, whereas total predator populations never exceeded 10,000/ha in insecticidal control fields. When insecticides were applied to Trichogramma release and check fields on August 12, predator populations were reduced in one wk to levels similar to those in insecticidal control fields.

Larval Parasitism. The fate of larvae collected from cotton fields during each of the three yrs is summarized in Table 4. In 1981, diseased larvae were collected predominately from three fields that had been treated with Heliothis NPV. In 1982, no NPV was applied and diseased larvae occurred predominately in late August and early September. Most were infected with Nenwuraja rileyi (Farlow) Sampson or an undescribed virus-like particle (Adams et al. 1979). In 1983, pathogenicity was low, but death due to unknown causes was high.
FIG. 7. Seasonal occurrence of square (a) and boll (b) populations in Trichogramma release (-----), check (——) and insecticidal control (— —) cotton fields near Clinton, NC (1983).
<table>
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<th>Years</th>
<th>June</th>
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<th>August</th>
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<td>276 (30.9%)</td>
<td>885 (50.1%)</td>
<td>258 (34.5%)</td>
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<td>138</td>
<td>24</td>
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<td>617</td>
<td>1073</td>
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a/ % parasitized = no. parasitized/(no. parasitized + no. completed development + no. escaped).

b/ Includes diseased and injured larvae.

Percentage parasitization of field collected larvae was greatest in 1982 (50.1%). Nine species of larval parasites and one larval-pupal parasite, Archytas marmoratus (Townsend), were collected from BW/TBW infesting cotton. Microplitis croceipes (Cresson) comprised 90.6% of the parasites emerging from field collected larvae in 1981, 94.5% in 1982, and 57.9% in 1983. Cardiochiles nigriceps Viereck comprised 5.4, 4.1, and 36.1% of the emerged parasites in 1981, 1982, and 1983, respectively. The third most abundant parasite species was Cotesia (=Apanteles) marginiventris (Cresson) and it comprised 1.8, 1.1, and 1.5% of the emerged parasites in 1981, 1982, and 1983, respectively. Other parasite species occurred only rarely and included Campoletis flavinucius (Ashmead) (n=3), Pristomerus sp. (n=5), Leptesia sp. (n=2), and Meteorus sp. (n=1).

Egg parasitism. For a detailed description of egg parasitism in response to T. pretiosum releases, see Lopez and Morrison (this monograph). In 1981, 18 parasite releases were made at weekly intervals beginning June 10 and terminating August 17. During the F<sub>2</sub> (July 6 to 13) and F<sub>3</sub> (August 3 to 17) egg periods, releases were made at two to three day intervals. Release rates averaged approximately 105,000 emerged adult parasites/ha/release. Egg parasitism averaged 35% in release fields with 60-80% parasitism being achieved in some fields, particularly during oviposition periods. Egg parasitism in 1982 was low and because BW/TBW larval populations were increasing rapidly along with fruit damage after July 4, insecticide applications were initiated in all Trichogramma release fields. In 1983, parasites were released seven times at the rate of ca. 306,000 emerged adult parasites/ha/release from July 26 to August 10. Egg parasitism averaged 40 to 60% in the release fields, but declined sharply after releases were terminated and insecticides applied for boll weevil and BW/TBW control on August 12.

Yield and Insect Control Costs. Cotton production practices were similar among growers and results indicated that land preparation, fertilization, herbiciding, cultivation, defoliation, etc. were conducted independent of the particular BW/TBW management program employed and did not differ significantly between programs within yrs. Yields, spray costs, total insect control costs, and revenue net of control costs are listed for the respective management programs (Table 5).
<table>
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<th>Program</th>
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<td>133.68 + 3.55</td>
<td>43.77 + 1.89</td>
<td>Total Insect Control Costs</td>
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<td>99.08 + 9.77</td>
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<td>Techinserta Release</td>
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**Table 2:** Cotton Line Yield, Spray Costs, Total Insect Control Costs, and Revenue Net of Control Costs.
Analysis of yield in 1981 revealed no significant (P>0.06) difference in yield between programs. Insecticidal control fields yielded significantly (P<0.10) more than check fields in 1982. In 1983, insecticidal control fields yielded significantly (P<0.10) more than Trichogramma release fields while the check fields yielded significantly (P<0.15) less than fields receiving periodic releases of T. pretiosum.

Spray costs (insecticide + application cost) were incurred in Trichogramma release and check fields for each of the three yrs of the pilot test. Pollar applications for thrips and plant bugs (1981 and 1982 only) were made in a few fields, however boll weevils required control measures in all fields, all yrs. Number of applications for BW/TBW control for programs each yr are given in Table 1. In 1981, applications for BW/TBW control in Trichogramma release fields were made between release periods when larval populations exceeded established economic threshold levels. Two of the eight check fields in 1981 were inadvertently sprayed for BW/TBW larvae, thus a small proportion of the sprays costs reflect this occurrence. Check fields in 1982 received no applications for BW/TBW populations and most of the spray costs in insecticidal control fields were incurred as a result of applications for BW/TBW larval control. In 1983, no applications for BW/TBW control were made in Trichogramma release fields until parasite releases were terminated (August 10). At that time, all Trichogramma release and check fields were treated for boll weevil and BW/TBW populations.

Total insect control costs in Trichogramma release fields reflect spray costs plus the additional costs for the parasites and their distribution to fields. In 1981, total insect control costs were about $100/ha more in Trichogramma release fields compared to insecticidal control fields, with more than $120/ha of the total attributable to costs for the parasite plus its application. In 1983, costs incurred in using the Trichogramma augmentation technology were calculated at $80.32/ha. Total insect control costs in Trichogramma release fields were ca. $10/ha more than costs in insecticidal control fields.

Using a cotton lint price of $1.54/kg ($0.70/1b), the average revenue net of control costs was calculated. Differences in net revenue between treatments were small in 1981. Net revenue of control costs in 1982 averaged ca. $220/ha less in check fields compared to insecticidal control fields. In 1983, net revenue of control costs in insecticidal control fields averaged $236 and $163/ha more compared to revenue for check and Trichogramma release fields, respectively.

DISCUSSION

The test conducted in North Carolina in 1983 was the first time that greater yield in release fields has been shown over that of a non-release area in the U.S. Nevertheless, adequate suppression of BW/TBW was not achieved in Trichogramma release fields (1983) despite high rates of egg parasitism (see Lopez and Morrison, this monograph) and high levels of predator populations (Table 3, Fig. 8), nor were larval populations significantly reduced compared to check fields receiving no parasite releases. In 1981, no differences in yield were detected between the three programs and in 1982 insecticide interference precluded testing the Trichogramma release treatment. Factors constraining the technical and economic feasibility of controlling BW/TBW in cotton by augmentative releases of T. pretiosum are discussed below.
A model which accurately predicts onset and duration of oviposition periods as well as providing quantitative information on expected egg densities and larval numbers may be crucial to utilization of the augmentation approach with Trichogramma in the U.S. (see Witz et al., this monograph). Increasing captures of moths in pheromone traps did serve as an early alarm system to signal onset of an oviposition period in Arkansas and North Carolina. However, the traps were apparently more efficient in capturing moths at low densities (F1 and F2 generation) than at high densities (≥ F3 generation) because of competing pheromone sources, i.e., native females (Hartstack and Witz 1981).

Accurate prediction (short or long-term) of moth occurrence and egg density would facilitate timing of parasite releases. Egg density assessments via whole plant examination are laborious, time consuming, and variable. Between-field variability in egg populations necessitates frequent (< 3 days) scouting of individual fields because it is imperative that Trichogramma populations are augmented prior to egg hatch. Moreover, our inability to relate BW/TBW egg densities in cotton to subsequent establishment of larval populations (this study, Adkisson et al. 1964, Shipp and Earhart 1967) confounds decision-making for initiating and terminating parasite releases.

Knippling and McGuire (1968) theorized that maintenance of 80% egg parasitism is essential to stabilize a host population at subeconomic levels. Parasitism of BW/TBW eggs in cotton dramatically increased following releases of T. pretiosum (see Lopez and Morrison, this monograph) and 80% parasitism was achieved in some fields, but never sustained for the duration of a BW/TBW oviposition cycle. This level has been attained in small cotton plots in the U.S., but only in one instance (Stinner et al. 1974) was the test replicated and larvae significantly (66-80%) suppressed.

The virtual absence of BW/TBW eggs between oviposition periods as well as their low densities during initial generations were inadequate for in-field reproduction of T. pretiosum in appreciable numbers. Moreover, adult survivorship was only 0.5-4.0 days (Keller and Lewis, this monograph) and since BW/TBW eggs hatch within 72 h at mean temperatures similar to those normally occurring within the cotton canopy (Fye and McAda 1972), parasite releases were conducted at 2-3 day intervals to ensure a continued high number of searching parasites. In developing a subroutine for modeling the population dynamics of Trichogramma for incorporation in the MOTHZV model, Hartstack et al. (1976) assume an adult longevity of 10 days. This figure is substantiated by Nordlund et al. (1976) where they report that T. pretiosum females held at 26°C lived 10.6-12.2 days depending on exposure to BW moth scales. Thus the possibility does exist, assuming a higher quality, longer-lived parasite, that intervals between releases could be increased which would result in decreased parasitoid costs.

The capability for maintaining BW/TBW populations below treatment thresholds in cotton through augmentative releases of T. pretiosum was tested only in 1981 and 1983. In 1982, after release fields were sprayed with broad-spectrum insecticides, egg parasitism in response to releases became erratic or was not evident, thus, further attempts to mass release this parasite were terminated. Inconsistencies in egg parasitism levels during 1981 and 1983 suggest that insecticidal treatments in fields nearby those receiving releases of T. pretiosum may have been detrimental to parasite performance. In reviewing previous studies which tested sensitivity to pesticides by Trichogramma, Bull and Coleman (this monograph) reiterate that this genus is generally highly susceptible to most chemical insecticides.
and that lethal effects may be manifested as a result of direct exposure to spray applications or drift of pesticides as well as from posttreatment contact with pesticide residues on foliage which may remain toxic for several to many days. Failure to achieve an initial and sustained high rate of egg parasitism by *T. pretiosum* at the onset of BW/TBW oviposition and during egg laying periods often resulted in an accumulation of larvae and damaged fruit, which during 1981 and 1982, required insecticide treatments. (In 1983, release fields were not treated with insecticides during release periods because of an indemnification agreement between the USDA-ARS and grower.) Unfortunately, there were no larvicides acceptable to participating growers which are non-toxic to *T. pretiosum*. Microbial insecticides for BW/TBW management, though having good potential for integration with *Trichogramma* releases (Bull et al. 1979), were rarely used by growers based on their previous experience with these materials relative to erratic control or poor efficacy. Once an insecticide such as those primarily used in most cotton production schemes in the U.S. is employed, its extended persistence adversely affects searching *Trichogramma* (as well as other entomophages) and precludes full benefits to be derived from parasite augmentation.

Insecticides applied to release fields for control of BW/TBW, plant bugs, and boll weevils increased insect control costs over those attributable to costs for *Trichogramma* and their distribution to fields. Nevertheless, insect control costs in 1981 were greatly inflated because parasite applications were made at weekly intervals with little regard for host egg densities. Difference in insect control costs between release and insecticidal control fields was slight ($8/ha) in 1983. Potential differences could have been much greater since our cost estimates for *Trichogramma* ($0.0178/1000 adults) are based solely on production cost figures. Prices charged by commercial suppliers of *Trichogramma* for pest control are 2-14 times higher than our cost estimates since these firms incur marketing expenses and must realize a profit.

Yields in release fields in 1983 were ca. 100 kg/ha less than in insecticidal control fields which amounted to $163/ha less net revenue of control costs. This reduction in potential yield in the 1983 release fields was, in part, apparently the result of fruit loss due to untreated BW/TBW larvae which had developed from very low egg densities in late June and early July. Also, fruit compensation potential was probably affected by a severe, concurrent drought. Releases of *T. pretiosum* were not conducted during this oviposition period and this decision was based on biological and economical considerations. Of primary importance was the expected poor efficacy of the released parasites in a contaminated environment; azinphosmethyl had been applied to all release fields for overwintered boll weevil control on June 20 and 27 and field cage studies by D. L. Bull (see Bull and Coleman, this monograph) show that *T. pretiosum* adults are severely affected by 5-day old residues of azinphosmethyl. Moreover, since egg densities were too low for released populations of *T. pretiosum* to maintain itself, further releases would have been required and increased costs for the parasite and its application would further limit economic feasibility. Yield potential in the 1983 release fields was also affected by boll weevil populations which began to increase rapidly around August 1. These damaging populations were effectively suppressed in the insecticidal control fields while *Trichogramma* release fields remained untreated for an additional 10 days in an attempt to evaluate the feasibility of maintaining BW/TBW below treatment threshold levels.

The need for maximizing the impact of naturally-occurring entomophages for effective use of *Trichogramma* in augmentative releases has often been stressed (see papers in Ridgway and Vinson 1977). Ridgway et al. (1981)
developed a series of decision-making indices to derive the number of Trichogramma and naturally-occurring predators/unit area needed to prevent loss due to BW/TBW on cotton. Our data indicate that there were, in general, higher numbers of predators in Trichogramma release and check fields than in insecticidal control fields each of the three years.

Predator populations probably did contribute to maintaining BW/TBW populations below subeconmic levels in 1981. However, predator populations were so low in 1982 that they probably contributed little to suppression of BW/TBW. These low level predator populations in 1982 were the result of azinphosmethyl applications in June, and because these applications were area-wide, predator populations never recovered. Reduced predation of BW/TBW eggs and larvae in June 1982 may have resulted in higher populations during the F2 egg-larval generation (July). However, Hartstack et al. (1983) had predicted relatively high egg densities in early July based on pheromone trap captures of F1 generation moths in June (also see Witz et al., this monograph).

Predator populations in cotton were higher in North Carolina (1983) than either of the previous two yrs in Arkansas despite azinphosmethyl applications in June for control of overwintered boll weevils. Predator populations in test fields during late June to early July were similar to numbers observed in 1979-80 in fields in the same general area as the 1983 test (Lloyd et al. 1981). In southern North Carolina one application of insecticide is often applied to the F1 egg-larval generation (July) in cotton (Bacherler, 1985), even in absence of azinphosmethyl applications. In this highly diversified agroecosystem (contrasted with that of the Mississippi River delta), cotton constitutes only a small portion of the total area and field corn is the predominant crop (Stinner et al. 1976). Large numbers of natural enemies present in corn and other habitats disperse to the surrounding, small cotton fields as well as to other local crops.

Adequate suppression of BW/TBW was not achieved in Trichogramma release fields (1983) despite high rates of egg parasitism (see Lopez and Morrison, this monograph) and high levels of predator populations (Table 3, Fig. 8), nor were larval populations significantly reduced compared to check fields receiving no parasite releases. In fact, the BW/TBW larval population in the check and Trichogramma release fields would have continued to increase if insecticide applications had not been initiated on August 12 as part of the Boll Weevil Eradication Program.

Lingren and Wolfenbarger (1976) reported depressed levels of parasitization in field cages by T. pretiosum because of predation on parasitized TBW eggs by Orius insidiosus (Say) and stated that T. pretiosum exerted its major effect on TBW populations at low O. insidiosus densities. Jones et al. (1977) reported 91% and 98% predation of BW/TBW eggs at four and seven days, respectively, in the presence of high predator populations and suggested that the potential of parasitized eggs producing additional T. pretiosum parasites (recycling) was greatly reduced. Jones et al. (1979) later demonstrated high rates of parasitism (55-84%) for a sustained period and suggested that the virtual absence of entomophagous arthropods probably allowed T. pretiosum to recycle for two complete generations. Despite a slight preference by Chrysopea carnea Stephens for unparasitized over T. pretiosum parasitized TBW eggs under laboratory conditions, S. B. Stark (pers. comm., USDA, ARS, P. O. Box 225, Stoneville, MS) concluded that predation of unparasitized eggs may actually be lower than for parasitized eggs due to the longer developmental time (ca. 2.5 x) of the latter. Thus, augmentation of T. pretiosum populations for control of BW/TBW may be less effective in terms of numbers of host eggs killed/released parasite when populations of egg predators are present than when absent.
The high % emergence of hymenopterous parasites from field collected BW/TBW larvae was not anticipated. These levels, particularly in the mid-south, were greater than any reported in cotton since the advent of organochlorine insecticides in the 1940's (Watson et al. 1966, Lewis and Brazzel 1968, Shepard and Sterling 1972, Smith et al. 1976, Burleigh and Farmer 1978, and Pairs et al. 1982). Hopper and King (1984) reported that early instar TBW larvae moved and fed less often on the cotton plant and damaged fewer (ca. 75%) fruiting structures after parasitization by Microplitis croceipes. This species was the most abundant parasite reared from field collected larvae each yr. We attribute our failure to detect differences in levels of larval parasitism between BW/TBW control programs to the mobility of the parasites and their apparent relative insensitivity to some of the newer insecticides used, particularly the synthetic pyrethroids. For example, when Powell and Scott (1985) caged M. croceipes adults on cotton plants after application of the synthetic pyrethroid flucythrinate, mortality was no greater than in an untreated check (7.5 vs. 3.7%); and only 20.8% were killed when exposed to fenvalerate residues. These studies and data reported herein suggest that the impact of larval parasites on feeding and population suppression can be substantial and further studies are warranted with the objective of conserving and utilizing these parasites for managing BW/TBW populations.

Results of this study are in agreement with those reported by Twine and Lloyd (1982). They reported that a mean egg parasitism rate of 47.4% of Heliothis spp. by Trichogramma nr. pretiosum augmented in cotton was insufficient to provide adequate control of Heliothis. However, reconciling the putative success of augmentative releases of Trichogramma spp. to manage Heliothis spp. in cotton in other countries is difficult. For example, Anonymous (1984a) lists Colombia, Peru, and the USSR as countries using augmentative releases of Trichogramma spp. to manage Heliothis spp. in cotton and Jimenez (1980) and Li (1985) report the use of Trichogramma spp. to manage Heliothis spp. in cotton in Mexico and China, respectively. We suggest that Trichogramma is used in countries such as the USSR and China because it is cost effective relative to alternative means of control. For example, in China, most large scale Trichogramma production facilities use eggs from silkworm [Antheraea pernyi Guerin-Meneville or Samia cynthia ricini (Boisd.)] produced as a by-product from the silk production industry (King and Morrison 1984). In the USSR, Trichogramma spp. are mass produced on Angoumois grain moth eggs. So, in each case there is the capability for mass producing the parasite cheaply - within the country. In contrast, within the US, the current availability of easily used, cost effective, broad spectrum insecticides deters use of the Trichogramma augmentative technology. Importation of these same chemicals into countries such as China requires currency acceptable on the world market; thus, expense of the chemical is increased and it may not be available. Additionally, each cotton-producing state in the US generally describes procedures for controlling BW/TBW in cotton with insecticides being applied based on an established economic threshold, with few insects tolerated, e.g., only four larvae/100 plants in July cotton (Anonymous 1984b). Since economic thresholds are dynamic, other countries may be more tolerant of Heliothis populations based on the price for insecticide control as well as other considerations. Finally, Trichogramma may be more effective against Heliothis spp. in other countries such as the USSR and China. In China, mass reared Trichogramma are required to fly in search of host eggs in the insectary, thereby continually eliminating weak, sedentary individuals (King and Morrison 1984). Huo Shotang (pers. comm., Academy of Agricultural Sciences, PRC) stated that ca. 100,000 ha of cotton are treated annually for H. armigera (Hubner) in Shaanxi Province by release of

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T. confusum Viggiani. The parasites are applied in early season during the
F₂ generation at the rate of 120,000/ha at three to four day intervals for
a total of three releases and ca. 75% egg parasitization is obtained by
these releases. The Trichogramma are released in cotton by rolling the
leaf around parasitized eggs glued to cards. Recent reports from the USSR
(Kamalov 1982, Kovalenkov 1984) indicate that T. euproctidis (Girault) is
being released for control of H. armigera in cotton. Kamalov (1982) did
state that the insectary strain of Trichogramma was prevented from
deteriorating by rearing on Ephesia kuehniella Zeller three times/year.
Perhaps, development of an in vitro method of rearing on a highly nutri-
tious diet for Trichogramma spp. will enable economical production of a
consistently high quality product in the USA that will live longer and
parasitize a greater percentage of BW/TKW eggs in cotton fields.
Certainly, usage of Trichogramma, regardless of crop, will require the
development of a pest management system that typically uses nonchemical
methods for control of pests not attacked by Trichogramma; that fully uti-
ilizes other natural enemies; and as a last resort uses insecticides that
are relatively nontoxic to Trichogramma and/or apply them in a highly
selective manner.

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