INTRODUCTION: BIOLOGICAL CONTROL OF HELIOTHIS [1] SPP. IN COTTON BY AUGMENTATIVE RELEASES OF TRICHOGRAMMA [2]

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ABSTRACT

The bollworm, Heliothis zea (Boddie), and tobacco budworm, H. virescens (F.), are major insect pests of cotton in the USA. These pests have exhibited varying levels of resistance to most classes of insecticides. Resistance to the widely-used synthetic pyrethroids has not been documented in this country, but there are reports of substantial increases in tolerance by tobacco budworm. Consequently, there has been much interest in reducing dependence on insecticides for their control. Trichogramma spp., augmentatively released, have often been proposed as a therapeutic method for managing Heliothis spp. in cotton. We describe here a 3-yr pilot test conducted in southeast Arkansas (1981-1982) and North Carolina (1983) to evaluate the feasibility of this biological control approach. Test components included mass rearing and release of the parasite; extensive field evaluation of parasite releases by measuring parasitization, other entomophage populations, Heliothis spp. populations, pest damage, and yield response; Trichogramma movement and behavioral manipulation; pesticide effects on Trichogramma; modeling of T. pretiosum Riley augmentative releases; and systematics of Trichogramma, including surveys for egg parasites. Additionally, the ability to monitor and predict the occurrence of Heliothis spp. adults using pheromone trap captures and a simulation model was assessed. Results of this 3-yr test will help define future prospects for Trichogramma augmentative release technology and serve as a guide for research.

INTRODUCTION

Heliothis spp. are among the most important insect pests in the world and are a global problem between 45°N and 45°S latitude (Hardwick 1965). Two species, Heliothis zea (Boddie) (tomato fruitworm, corn earworm, or bollworm) and H. virescens (F.) (tobacco budworm) annually account for losses of over $1 billion in the USA by attacking cotton, corn, soybean, tobacco, and vegetables (Agric. Res. Serv. 1976). Schwartz and Klassen (1981) used test plot data to estimate that Heliothis spp. could cause 12% loss in cotton yield with the best insecticide alternative and 91% without insecticide control. During 1981, the tobacco budworm and bollworm accounted for an estimated 41,500 cotton bales lost in Mississippi and

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323,710 bales lost in cotton-producing states. In addition to these losses, the cost for controlling the bollworm and tobacco budworm was about $114/ha in the Mississippi Delta (Simpson 1983).

Cotton losses to the bollworm, tobacco budworm, and other Lepidoptera were so severe in 1977 that Cotton Inc. initiated a series of special regional meetings to assess the problem and obtain recommendations from appropriate personnel. The propensity of the tobacco budworm for developing resistance to insecticides had been well documented (Clower et al. 1975, Harris et al. 1972) and economical control of high density populations of the tobacco budworm in cotton was no longer possible at that time with currently registered insecticides. Consequently, cotton producers have been interested in pest management practices that might enable them to control pests with less dependence on heavy usage of chemical pesticides (Bottrell and Adkisson 1977).

It is generally accepted that a key component of all integrated pest management strategies is the conservation and attendant maximum use of naturally occurring beneficial organisms to increase crop production. In crop situations where natural enemies have not been depleted by insecticides applied for control of pests such as the cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter), boll weevil, *Anthonomus grandis* Boheman, *Lygus* spp., and pink bollworm, *Pectinophora gossypiella* (Saunders), it is not unusual to find populations of bollworm and tobacco budworm held to non-economic levels by existing natural enemies (Laster and Brazzel 1968, Dinkins et al. 1970). However, even under the best conditions, these natural enemies may not effectively suppress *Heliothis* spp. and therapeutic measures are required to save the crop. Usually, this involves the initiation of chemical controls, which decimate natural enemy populations and may lock the producer into an expensive program of multiple applications of insecticides.

Propagation and release of *Trichogramma* spp. in cotton and other crops has been suggested as a possible alternative to insecticides (Flanders 1930). Perhaps the most comprehensive reviews on *Trichogramma* usage available at the time the pilot test was proposed were in Ridgway and Vinson (1977). There, usage of *Trichogramma* in augmentative releases was reviewed for the Western Hemisphere by Ridgway et al. (1977), for China by Huffaker (1977), and the USSR by Beglyarov and Smetnik (1977).

Worldwide interest in, and usage of *Trichogramma* spp. for control of lepidopterous pests has been most explicitly delineated during the last 5 yrs. Presently the most widely augmented entomophagous arthropod in the world, *Trichogramma* spp. have been released on 8,000,000 ha in the USSR (Voronin and Grinberg 1981) and 2,000,000 ha in the People's Republic of China (Li 1985). Other countries using *Trichogramma* are Mexico (651,012 ha; Jimenez 1980), USA (200,000 ha; Ridgway et al. 1981), Colombia (104,049 ha; Hassan 1983), Taiwan (63,563 ha; Chiang et al. 1980), India (5,000 ha; Hassan 1983), South Africa (2,000 ha; Hassan 1983), Federal Republic of Germany (648 ha; Hassan 1982), and Switzerland (300 ha; Hassan 1983). Species of *Trichogramma* reared and released differ among countries, as do the target pests. Apparently, *Trichogramma* is most frequently used against stem borers, particularly in situations where they are the sole pest of a crop. For example, *Trichogramma* has been released to control *Ostrinia* spp. in China (Li 1985), the USSR (Voronin and Grinberg 1981, Zil'berg 1972), and the Federal Republic of Germany (Hassan 1982); to control stem borers in sugarcane (Chiang et al. 1980, Li 1985), and rice (Li 1985); and for control of caterpillar pests of certain vegetables (Parker and Pinnel 1972, Voronin and Grinberg 1981). In China, *T. dendrolimi* Matsumura is released annually over 1,000,000 ha of forest for control of *Dendrolimus* spp. (Li 1985).

The technical feasibility of suppressing *Heliothis* spp. larval populations in cotton by augmentative releases of *Trichogramma* was tested in 1970 using three manual releases of 494,000 adult *Trichogramma*/ha (P. D. Lingren and J. G. Kim, Brownsville, TX; unpublished information). This resulted in ca. 60% parasitism of high *Heliothis* spp. egg densities, and provided control for over a month both in and near the release area. Aerial releases of 123,500-247,000 adult *Trichogramma*/ha resulted in an average 51% parasitism of *Heliothis* spp. eggs on five Texas cotton farms (Ridgway et al. 1977). Stinner et al. (1974) evaluated the technical feasibility of reducing *Heliothis* spp. larval populations in cotton by releasing *T. pretiosum* Riley. Although parasite release rates were high (up to 957,000/ha), these authors did not present either damage reduction or yield response. Other examples of biological control of *Heliothis* spp. in cotton in the USA by augmentative releases of *Trichogramma* are given in Table 1. Data reported by Oatman and Platner (1971, 1978) demonstrate the technical feasibility of augmenting *T. pretiosum* populations to reduce damage in tomato caused by the tomato fruitworm, cabbage looper, *Trichoplusia ni* (Hubner), and *Manduca* spp. However, these authors also found there was a need for chemical control of other pests not attacked by *T. pretiosum*.

In 1981, the U.S. Dept. of Agric., Agric. Res. Serv., initiated a pilot test in cooperation with the University of Arkansas to evaluate the feasibility of managing *Heliothis* spp. in cotton by augmentative releases of *Trichogramma*. Impetus for the pilot test had been provided by the urgent need during the mid-1970's to develop nonchemical methods for controlling *Heliothis* spp., particularly the tobacco budworm in cotton, which was not being sufficiently controlled by insecticides. During the same time period (as early as 1976), at least four firms were producing and aggressively marketing *Trichogramma* for insect control, particularly in cotton, even though existing data were insufficient to correlate augmentative release rates with subsequent parasitization rates, larval population suppression, damage reduction, or yield. Comparisons of the relative efficacy of *Trichogramma* augmentative releases to insecticide treatments or untreated controls were also lacking. The level of parasitization relative to release rate was also highly variable. In fact, concern was sufficiently great about the use of *Trichogramma* for augmentative releases that the Agric. Res. Serv. sponsored the workshop "*Trichogramma* Research and Development Conference: Status and Use Strategies", in Atlanta, GA, in December 1978, to clarify the status of technology on *Trichogramma* and develop strategies for its use in managing pest populations. Workshop proceedings included statements on current policy toward utilization of *Trichogramma* by the Agric. Res. Serv., state research, extension, and agricultural consultants. Prior to this conference, the National Program Staff, Agric. Res. Serv., issued a statement entitled "Status and Potential for Production and Use of Biological Agents for Pest Control". In this report, *Trichogramma* usage in augmentative releases was singled out as an example. It was stated that "even with improved understanding of many factors that influence rearing, distribution, and host finding efficiency of *Trichogramma*, large numbers must still be released under controlled conditions to obtain consistent results. In addition to numbers released, the effectiveness of *Trichogramma* is also influenced by other factors such as: (1) density of the pest; (2) species or strain of *Trichogramma* released; (3) vigor of the parasite released; (4) method of distribution; (5) crop phenology; (6) number of other biological agents present; and (7) proximity of insecticide use." It was further stated that "careful consideration of a number of complex factors is essential in determining whether or not adequate arthropod pest control can be obtained with the use of commercially available entomophagous arthropods. Reliance upon use of entomophagous

TABLE 1. Biological Control of *Heliothis* spp. in Cotton in USA by Augmentative Releases of *Trichogramma*

Release rate/ha [a] (1000's)	No. eggs/ha (1000's)	% parasitization		Control evidence	Reference
		Release (treated)	Check or pre-release		
494	-	58	11	-	Lingren & Kim (unpublished data)
46-957	7-28	33-81	5-7	66-80% reduction *Heliothis* larvae	Stinner et al. 1974
124-247	-	24-73	0-7	-	Ridgway et al. 1977
176	.5-2.8	2-43	5-27	-	Jones et al. 1977
176	2-16	3-73	1-9	-	Jones et al. 1977
112-178	15-17	55-84	17-81	21% reduction *Heliothis* larvae	Jones et al. 1979
111	42-242	15-90	15-90	Reduced *Heliothis* larvae	Ables et al. 1979
47	-	42-80	32-72	Inadequate larval suppression	Luttrell et al. 1980

a/ Releases typically made at 2-4 day intervals for several applications.

arthropods to control pests should be limited to those situations where scientifically, environmentally, and economically sound procedures are available." Workshop participants agreed a complete evaluation of available fundamental and applied Trichogramma technologies, their integration with agronomic practices, and the subsequent transfer of these technologies to commercial applications would require extensive large scale field trials. It was recommended that "additional resources should be made available for conducting large scale evaluations on biologically controlling Heliothis spp. and other lepidopterous pests by augmentative releases of Trichogramma beginning no later than October 1, 1981. Such tests should include experiments designed to evaluate such aspects of Trichogramma performance as a) comparing Trichogramma reared on the target host and insectary host, b) rates of parasite release, and c) effects and benefits of semiochemicals and/or host eggs on these parameters. Evaluation of application and release technology should also be made along with an economic feasibility study".

The first test proposal "Pilot testing of a unified system for using Trichogramma to manage lepidopteran pest populations in cotton and soybean with emphasis on Heliothis spp.: an areawide approach" was proposed as a possible component of the U.S. Dept. Agric., Animal and Plant Health Inspection Service Boll Weevil Eradication Research and Biological Evaluation Trial Program in Chowan, NC. Another area tentatively identified as a test site was Coy, AR. This proposal was not approved, but a second proposal "Management of Heliothis spp. in cotton by augmentative releases of Trichogramma" submitted in 1979 was approved for funding beginning October 1, 1980.

The primary objective of the approved pilot test was "to evaluate on a large scale, in replicated field experiments, current technology for augmenting and manipulating Trichogramma populations to manage Heliothis spp. in cotton". Technological advances considered in development of this proposal were as follows:

(1) The taxonomy of the North American species of Trichogramma was clarified when neotypes were designated for T. pretiosum and T. minutum Riley and lectotypes were designated for several species often confused in the past literature (Pinto et al. 1978).
(2) A system for mass producing T. pretiosum on Angoumois grain moth, Sitotroga cerealella Olivier, eggs was developed that yielded individual parasitized eggs unattached to a substrate (Morrison et al. 1978).
(3) A delivery system to precisely meter and dispense bulk quantities of S. cerealella eggs containing Trichogramma pupae was developed and successfully used to aerially broadcast parasites in the field (Bouse et al. 1981).
(4) Sex pheromones of Heliothis spp. were identified (Klun et al. 1979) and traps designed (Hartstack et al. 1979) that enabled detection of moths 2 to 3 days in advance of oviposition onset. Moreover, a computer simulation model for predicting the occurrence of Heliothis spp. (Hartstack et al. 1976) based on catches of moths in pheromone traps had been developed.
(5) Several investigators had collected data demonstrating increased egg parasitism of Heliothis spp. in cotton following parasite releases (see Table 1).
(6) Chemical cues mediating host seeking behavior of Trichogramma were elucidated (Lewis et al. 1972) and a system for applying supplemental sterile Heliothis eggs plus kairomones to restrict dispersal and improve searching efficiency of Trichogramma was described (Gross et al. 1981).

(7) Recent results indicated that there was little difference in field parasitization rates between *Trichogramma* reared on Angoumois grain moth eggs or other lepidopterans with larger eggs (Hassan et al. 1978; R. E. Furr, Stoneville, MS, unpublished data).

(8) Finally, boll weevil populations were at a low ebb in many areas, particularly in parts of North Carolina where it had been suppressed to nondetectable levels.

Portland, AR was selected as the pilot test site after careful deliberation by scientists developing the proposal as well as scientists representing alternative sites (Chowan County, NC and Florence, SC). Other sites discounted included Pontotoc County, MS and College Station, TX. Criteria considered in selection of Portland as a test site were (1) availability of cooperating farmers, (2) consistently high *Heliothis* spp. populations, (3) control over the use of pesticides, (4) representative of cotton producing areas, (5) availability of support personnel, (6) availability of facilities and equipment, (7) likelihood of state and other agency (viz., Animal and Plant Health Inspection Service, U.S. Dept. Agric.) participation, (8) availability of background information on location, (9) favorable logistics including personnel travel and shipment of parasites from College Station, TX, (10) presence of low boll weevil populations, and (11) availability of isolated cotton fields for replication. The Portland community was similar to one described by Phillips and Nicholson (1979) and was characterized as a high *Heliothis* spp. hazard area and an extremely low boll weevil population area.

Unfortunately, the boll weevil became a major pest within the Portland community during 1981 and 1982 as it did throughout the mid-south and southeastern USA. Consequently, insecticides were applied for control of the boll weevil and this was a major impediment to evaluating *Trichogramma* augmentation technology. Thus, it was agreed that the third year of the test should be relocated. The site selected was near Clinton, NC in the Boll Weevil Eradication Buffer Zone. The objective of the relocation was to optimize *T. pretiosum* survival, reproduction, and suppression of *Heliothis* spp. in cotton. Specific reasons for selecting the alternate test site were as follows:

(1) Insecticide usage in fields selected to receive parasite releases was not expected since boll weevil populations had been greatly reduced due to eradication efforts and plant bugs were not considered a pest. Also, in contrast to the previous two years, a provision for remunerating potential yield loss was to be negotiated to preclude the participating grower's use of insecticides for *Heliothis* control in *Trichogramma* release and untreated control fields. Moreover, insecticidal drift from nearby treated cotton fields was expected to be minimal since the grower used a high clearance ground sprayer for applying insecticides.

(2) Occurrence of a consistently high bollworm population that emerged from senescing corn and attacked cotton during late July assured the presence of a high host egg density for a sustained period with consequent damage to natural control fields and recycling of the parasite in release fields.

(3) Naturally occurring entomophagous arthropod populations were expected to be high and provide complementary suppression of *Heliothis* spp. populations in *Trichogramma* release fields; and

(4) Presence of many small cotton fields allowed the possibility of replicating discrete fields.

Unfortunately, populations of the boll weevil resurged at the North Carolina location, and forced the producer to use insecticides, which interfered with evaluation of Trichogramma releases. Nevertheless, Trichogramma releases were conducted and insecticide applications were withheld long enough to allow an assessment of Trichogramma augmentation technology for maintaining Heliothis spp. populations at subeconomic levels. Results of the third yr as well as the first 2 yrs are presented in subsequent sections of this monograph.

Results of the parasite releases are presented in section X and discussion of Heliothis spp. and naturally occurring entomophagous arthropod populations under different management programs are presented in section VIII. Insecticide usage for control of other pests, particularly the boll weevil, often compromised our ability to evaluate Trichogramma augmentative technology because chemicals used were generally toxic to T. pretiosum, either as residues on the plant for several days after application or in the form of drift from adjacent fields. These effects are discussed by D. L. Bull and R. J. Coleman in section XII. We did demonstrate the ability to consistently mass produce, transport, and distribute large numbers of Trichogramma over a large crop area. These areas and the new technology developed are reviewed by L. F. Bouse and R. K. Morrison in Sections V and III, respectively. Certainly, this new technology has worldwide application and is likely to be used for Trichogramma augmentative releases in many crop and pest situations. Development of a suitable diet and in vitro method for rearing the parasite could minimize production costs as well as produce a consistently high quality organism. Also demonstrated in the test was the ability to monitor and predict Heliothis spp. occurrence using pheromone trap captures and a simulation model. This area of the test is reviewed by J. A. Witz and co-authors in Section VII. Trichogramma pretiosum was used each of the 3 yrs for release, but criteria for selection of the proper species for release still have not been developed. A. C. F. Hung and co-authors present a discussion of Trichogramma systematics, as well as original data on the occurrence of egg parasites in the Portland, AR and Clinton, NC areas in section II. Research in the areas of systematics and behavior to improve our understanding of Trichogramma and its potential as a biological control agent is essential. The use of behavioral chemicals to manipulate Trichogramma populations is reported by W. J. Lewis and co-authors in section VI. The extent of movement of Trichogramma after release is often a major question. M. Keller and W. J. Lewis present data on movement of T. pretiosum after release during the third test yr in section IX and M. Keller and co-authors review movement behavior of Trichogramma spp. in general in section XI. Determining exactly when to initiate releases is complex since economic thresholds have not been established for Heliothis egg populations and computer simulated models will be required to assess the number of parasites required for release to achieve a desired level of control. Other factors, including the number of naturally occurring entomophagous arthropods present must be considered. Modeling of T. pretiosum augmentative releases is reviewed by J. Goodenough in section XIII. An overview of the pilot test and results of parasite releases were briefly reviewed by King et al. 1984.

Documented results on effectiveness of augmentative releases of Trichogramma spp. to control selected pests in corn and vegetable crops, including Heliothis spp. on tomato, indicate that such areas are promising for implementing the Trichogramma augmentative technology in the USA (Oatman and Platner 1971, 1978; Parker and Pinnell 1972; Kanour and Burbutis 1984). Results of the test reported in this monograph will help define the future prospects of this technology and aid in focusing research for its implementation. R. L. Ridgway and R. K. Morrison place these aspects in perspective on a worldwide basis in section XIV.

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