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# WORLDWIDE PERSPECTIVE ON PRACTICAL UTILIZATION OF TRICHOGRAMMA [1] WITH SPECIAL REFERENCE TO CONTROL OF HELIOTHIS [2] ON COTTON

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## ABSTRACT

Substantial research and development efforts directed towards the utilization of augmentative releases of the egg parasites, *Trichogramma* spp., for control of lepidopterous pests have been underway throughout the world for several decades. Research on *Trichogramma* is currently being conducted in over 20 countries and commerical utilization has been reported in over 10 countries. The most extensive practical use is reported from the Soviet Union and China. Several studies conducted throughout the world have indicated that consistent reductions in insect pest populations can be obtained by augmentative releases of *Trichogramma*. However, several barriers continue to exist, at least in the United States, that limit the practical use of *Trichogramma* for control of the bollworm, *Heliothis zea* (Boddie), and the tobacco budworm, *H. virescens* (F.), on cotton. Among these barriers are the short life-span of mass-reared parasites, mortality of parasites resulting from the insecticides used for control of insect pests other than *Heliothis*, and the lack of precise and practical survey and prediction methods for both *Heliothis* and their natural enemies.

Information obtained in Arkansas and North Carolina during a pilot test to evaluate augmentative releases of *Trichogramma* in 1981-83 contributed significantly to our knowlege of the population dynamics of *Heliothis* and their natural enemies. However, additional quantitative information on the relationships between numbers of different species of natural enemies and *Heliothis* and on other major factors regulating *Heliothis* populations are needed. Such information should make it possible to more precisely determine the potential for practical use of *Trichogramma* and to improve management programs for *Heliothis* that involve increased utilization of natural enemies.


## INTRODUCTION

Mass-rearing and augmentative releases of the egg parasites, *Trichogramma* spp., for control of lepidopterous pests have been pursued throughout the world for several decades. Research by Howard and Fiske (1911) and Flanders (1929, 1930) in the United States (U.S.) was particularly instrumental in stimulating research throughout the world. Comprehensive efforts were undertaken in the Soviet Union in the late 1930's (Meier 1937, 1941; Telenga and Shchepetil'nikova 1949) and in China in the early 1950's (Li 1982). Later, significant contributions on

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Trichogramma were reported from Europe (Stein 1960, Schutte and Franz 1961). Research in the U.S. was accelerated after the publication of an apprasial of the limitations and potentialities of the use of Trichogramma by Knipling and McGuire (1968).

Much of the emphasis in research on Trichogramma in the U.S. has been directed towards the development of augmentative releases of Trichogramma for control of the bollworm, Heliothis zea (Boddie), and the tobacco budworm, H. virescens (F.), on cotton. Emphasis has been placed on this application because of the need for a control method that would not destroy naturally occurring beneficial insects which regulate Heliothis populations and that could provide an alternative control method to insecticides if insecticide resistance were to render available insecticides impractical (Ridgway et al. 1973).

The advances toward the development of the practical use of Trichogramma for the control of Heliothis on cotton in the U.S. are discussed in the preceeding chapters of this monograph. These chapters report primarily on the results of a 3-yr operational pilot test conducted in 1981, 1982, and 1983 in Arkansas and North Carolina in areas where injurious populations of boll weevils, Anthonomus grandis grandis Boheman, occurred in each of the three years. The results from this pilot test indicate that several barriers still exist that limit the practical use of Trichogramma for control of Heliothis on cotton in the U.S. Still, considerable potential exists for utilizing the knowledge gained in this pilot test to develop the technology needed to use Trichogramma for control of insect pests on other crops, to establish the conditions under which Trichogramma might ultimately be used to obtain practical control of Heliothis on cotton in the U.S., and to utilize naturally occurring parasites and predators more efficiently in the management of Heliothis populations on cotton.

Therefore, in the final chapter of this monograph on Trichogramma, an attempt will be made to place the knowledge of Trichogramma in a broad perspective by briefly discussing three issues: (1) worldwide activities on Trichogramma, (2) barriers to expanded use of Trichogramma, and (3) the importance of quantitative population dynamics in determining the role of naturally occurring parasites and predators in the regulation of Heliothis populations.

## WORLDWIDE ACTIVITIES

Trichogramma research in most of the world has been previously reviewed in conjunction with several reviews of augmentations of natural enemies. These reviews were by Stinner (1977), by Beglyarov and Smetnik (1977) for the Soviet Union, by Huffaker (1977) for China, by Biliotti (1977) for Western Europe and by Ridgway et al. (1977) for the Western Hemisphere. Subsequent reviews provided additional information for the Soviet Union (Voronin and Grinberg 1981), China (Li 1984), and the U.S. (Ridgway et al. 1981). The many considerations, such as climate, kind of pests, labor costs, available technology, treatment thresholds, and institutional structures, that influence the feasibility of Trichogramma usage vary so much between different countries that generalizations on the effective use of Trichogramma are extremely difficult to make. However, the report that Trichogramma cultures are maintained in some 23 countries for research purposes and that Trichogramma are available commercially in some 14 countries reflects a continued and substantial worldwide interest in Trichogramma as a means of insect control (Table 1). Trichogramma have been used most commonly on corn (7 countries), cotton (5), sugarcane (4), sugarbeet (2) and cabbage (2) (Table 1) (Hassan 1984).

Information needed to estimate the benefits associated with Trichogramma usage throughout the world apparently is not available. However, in a number of circumstances researchers have consistently and

TABLE 1. Countries in Which Trichogramma are Reared for Research and Commercial Purposes (Adapted from Hassan 1984). a/

| Reared for research purposes, by country | | |
|---|---|---|
| Canada | Great Britian | Portugal |
| China | Greece | Rumania |
| Columbia | India | South Africa |
| Czechoslovakia | Italy | Soviet Union |
| Egypt | Morocco | Spain |
| France | Netherlands | Switzerland |
| Germany | Peru | United States |

Reared for commercial purposes, with target crop indicated

| Country | Crop |
|---|---|
| Austria | corn, cabbage |
| China | corn, sugar cane, rice, pine |
| Columbia | cotton, corn, sugar cane, soybeans, yucca, tomato |
| France | corn |
| Germany | corn |
| India | sugarcane |
| Peru | cotton, sugarcane, orange, apple, olive |
| Rumania | sugar beet |
| South Africa | citrus |
| Soviet Union | sugar beet, corn, pea, cotton, cabbage |
| Switzerland | corn |
| United States b/ | cotton, corn, soybeans, tomato, avocado |

a/ Status in Mexico and Taiwan is discussed by King et al. (1985a).
b/ Commercial use on tomatoes and avocado reported by E. R. Oatman (personal communication).

substantially reduced insect populations with field releases of Trichogramma. For instance, Hassan (1982) reported 65-93% reduction in larval infestations of the European corn borer, Ostrinia nubilalis Hubner, after Trichogramma releases for the years 1977 through 1981 in Germany; similar results have been reported from Switzerland (Bigler 1983, 1984). Substantial reductions in insect numbers and/or crop damage also have been reported for a wide range of insects and crops from both the Soviet Union and China (Voronin and Grinberg 1981, Li 1984). For example, in the Soviet Union, 60-80% reduction was reported for Agrotis sp., 72-80% for Loxostege sp., and 50-70% for Ostrinia sp. after releases of Trichogramma (Voronin and Grinberg 1981). Also, in China, 50-92% reduction was reported for Ostrinia sp., 70-98% for Heliothis sp. and 81% for Cnaphalocrocis sp.; 56-85% reduction in crop damage was associated with these reductions in insect numbers (Li 1984). Therefore, consistent reductions in pest populations following *Trichogramma* releases apparently provide a sound technical basis for practical utilization of *Trichogramma* against some insect pests in some parts of the world. On the other hand, variable results and insufficient reductions in pest populations have also been reported (King et al. 1984, 1985a, 1985b, Anonymous 1984).

## BARRIERS TO EXPANDED USE

Several research areas were identified in 1979 that were likely to be useful in removing technical barriers to the practical use of *Trichogramma* (Ridgway et al. 1981). These areas included (1) selection of the most effective species or strain, (2) reduction of loss of efficacy resulting from dispersal, (3) improvement of production and release efficiency, (4) increased knowledge of the relationships between the numbers of *Trichogramma* and pests and changes in yield, (5) improved prediction and survey methods for pests and naturally occurring predators and parasites, and (6) design and implementation of insect management systems that will eliminate or substantially reduce insecticide interference. Some progress has been made in most of these areas of research (Anonymous 1982) and all continue to be important. Three areas directly affecting *Trichogramma* have been selected here for discussion as major barriers to the practical use of *Trichogramma* with special reference to control of *Heliothis* in the U.S.: (1) insect quality, (2) production efficiency, and (3) insecticide interference. Two additional areas of research, (1) quantitative correlations of populations of predators and parasites with numbers of *Heliothis* eggs and larvae and (2) improved prediction and survey methods, will be discussed later in relation to quantitative population dynamics.

*Insect Quality*. Selection of the most appropriate strain and mass production of relatively long-lived parasites would significantly increase the probability of developing practical systems for use of *Trichogramma* to control *Heliothis* on cotton in the U.S. Although the knowledge of species present in cotton ecosystems has increased significantly (Hung et al. 1985), the criteria for selecting the most efficient strain have yet to be developed. Further, there is considerable evidence that the procedures for mass-rearing and manipulating *Trichogramma* emergence used in the pilot test reported in this monograph adversely affected the emergence, longevity, and searching ability of the parasite (Stinner et al. 1974b, Morrison et al. 1978). Also, available evidence indicates that mass-produced parasites live a relatively short period of time under field conditions (Keller and Lewis 1985, King et al. 1985b). A parasite that would effectively parasitize host eggs for more than 5 days rather than for 2-3 days would substantially improve operational feasibility and reduce cost. Careful studies of the longevity and searching efficiency of parasites reared from naturally occurring *Heliothis* eggs under field conditions would help provide insight on the prospects for mass producing more efficient parasites.

*Production Efficiency*. Long-term storage of the host or parasite during the mass production process could greatly reduce costs. Mass production facilities in the U.S. are now fully utilized for only a few weeks or few months during the year. If mass-rearing facilities could be operated continously at near capacity, both capital and labor costs would be substantially reduced. Although some progress has been made in the development of storage methods, substantial opportunity still exists for major advances (Li 1984). A possible alternative to the long-term storage of the host would be that of rearing the parasite on artifical diet. Again, some progress has been made but much remains to be done before an economical system is available (Gao et al. 1982).

*Insecticide Interference*. The application of insecticides for control of insect pests other than *Heliothis* on cotton and the drift of insecticides applied to nearby fields are perhaps the most important barrier to the practical use of Trichogramma for control of Heliothis on cotton (Ridgway et al. 1973, Stinner et al. 1974a, Bull and Coleman 1985, Lopez and Morrison 1985). In China, where Trichogramma are reportedly widely used, insecticide interference also is a major barrier to expanded use (Li 1982).

Insecticide interference probably will continue to be a major barrier to the use of Trichogramma on cotton in the U.S. But the successful areawide boll weevil management program in the southeastern U.S. provides the potential for greatly reducing, if not eliminating, the use of insecticides for boll weevil control in some major cotton-producing areas in the U.S. (Ridgway et al. 1985). This areawide boll weevil program has eliminated the use of insecticides for boll weevil on most of the cotton acreage in northeastern North Carolina (Carlson and Suguiyama 1985). This program has been expanded throughout North Carolina and South Carolina and possibly will be expanded throughout Georgia and parts of Florida and Alabama. The elimination of the boll weevil from some cotton ecosystems should provide new opportunties to utilize Trichogramma in conjunction with naturally occurring predators and parasites in the management of Heliothis populations.

## QUANTITATIVE POPULATION DYNAMICS

The information obtained during the pilot test conducted in North Carolina and Arkansas contributed significantly to our knowledge of the population dynamics of Heliothis and their natural enemies (King et al. 1985b, Lopez and Morrison 1985, Witz et al. 1985). However, the information is not adequate to develop a precise critical analysis of the potential for practical use of augmentative releases of Trichogramma for the control of Heliothis on cotton or to design highly efficient management programs for Heliothis that maximize the role of naturally occurring predators and parasites.

A brief review of our present knowledge of the population dynamics of Heliothis should provide a useful context for assessing information gaps and suggesting approaches to fill these gaps. Several valuable reviews, which contain considerable information on population dynamics of Heliothis, are available (Quaintance and Brues 1905, Anonymous 1972, Sterling 1979, Reed 1982). The work of Hartstack et al. (1976) and cooperators probably represents the most comprehensive effort directed towards the development of population models for use in the practical management of Heliothis populations. The prediction of the timing of oviposition by Heliothis with this model is useful as an aid in field scouting in some geographical areas (Hartstack et al. 1975, Hartstack and Witz 1983). However, predictions were less accurate than desired for managing augmentative releases of Trichogramma (Witz et al. 1985). Improvements in the model, particularly as related to host preference, fecundity, and movement of Heliothis adults, would increase the accuracy of predictions of the timing of oviposition and therefore increase the practical value of the model. Further, future efforts to validate Heliothis models and to study augmentative releases of Trichogramma would be greatly enhanced by field examination of cotton plants at least twice a week. Weekly inspections might fail to record large numbers of eggs since Heliothis eggs may hatch within 3 days.

One of the earlier attempts to quantitatively correlate predator populations with numbers of Heliothis larvae was reported by Ridgway (1969). Later, Hartstack et al. (1975) incorporated an attempt to quantify the relationship between naturally occurring predator populations and numbers of Heliothis larvae into a population model. In these studies, a high level of correlation (r=0.864) between numbers of predators and Heliothis larvae was identified from data collected in Frio County, Texas, as a part of large-scale evaluation of augmentative releases (Ridgway et al. 1973, Hartstack et al. 1975). This information was later used in the development of a predictive model (Hartstack et al. 1976). Later, Ables et al. (1983) attempted to improve the predator indices that might be utilized in population models. An attempt was made in 1979 to combine the effects of naturally occurring predators and releases of Trichogramma in order to develop decision-making indices needed to prevent the development of 2,500 large Heliothis larvae/acre (Ridgway et al. 1981). These theoretical indices were developed under the assumption that the effects of predation and egg parasitism were additive. This assumption was used even though there was evidence that it was not valid (Lingren and Wolfenbarger 1976) because available experimental information that could be used as a basis for predicting the interaction between predators and parasitized eggs was limited. Although the importance of understanding the relationship between parasitized Heliothis eggs and naturally occurring predators has been recognized (King et al. 1985b), quantitative field studies have not yet been conducted. Also, additional efforts are needed to more precisely quantify the role of naturally occurring predators and parasites on Heliothis under field conditions, independent of augmentative releases. Previous efforts on quantification of such relationships (Ridgway et al. 1967, Hartstack et al. 1975, Ables et al. 1983) and on sampling (Sterling 1979, Smith et al. 1983) provide useful information, but precise sampling of Heliothis eggs and larvae and of predators and parasites in conjunction with quantitative population modeling are needed, in order to adequately define relationships. After the relationships have been defined, the prospects for developing improved survey and prediction methods for use in Heliothis management programs will be substantially improved.

The potential value of the development of an improved understanding of the quantitative numerical relationships between Heliothis and their natural enemies can be illustrated by results of the areawide cotton insect management program in the southeastern U.S. Insecticide applications in the original boll weevil eradication evaluation zone averaged about 9.95/yr for control of all cotton insects prior to the initiation of eradication efforts (1974-1977) compared to slightly over 2.26/yr, including 1.86/yr for Heliothis control and 0.40/yr for diapause boll weevil control, after the program was initiated (1979-82) (Carlson and Suguiyama 1985). Direct evidence of the effects of greatly reduced insecticide use in the original eradication trial zone on Heliothis populations is not available. However, peak numbers of Heliothis captured in 10 light traps in the eradication zone were about 4,000/yr prior to initiation of the program (1976-1977) and less than 1,000/yr thereafter (1979-1982) (Carlson and Suguiyama 1985); and considerable experimental evidence shows that insecticides applied for control of the boll weevil and other cotton insects will substantially reduce predators and parasites of Heliothis and may result in substantial increases in Heliothis populations (Ridgway et al. 1967, Ridgway 1969, van den Bosch 1971).

Thus, a very strong justification exists for obtaining additional quantitative information on the relationships between the numbers of different species of natural enemies and Heliothis populations. Such information will be invaluable in more precisely determining the potential for practical use of Trichogramma and in designing improved management programs for Heliothis that involve increased utilization of naturally occurring predators and parasites.

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