Development and use of a biological control — IPM system for insect pests of crucifers

K. Duane Biever
Biever Consulting, 1 South 36th Avenue, Yakima, Washington, 98902, USA

Abstract
An effective biological control-integrated pest management (BC-IPM) system that maximizes biological control of *Plutella xylostella* (L.), *Artogeia rapa*e (L.), and *Trichoplusia ni* Hubner) has been developed. In the first phase, chemical insecticides were replaced by the judicious use of the microbial insecticide *Bacillus thuringiensis*; there was an immediate reduction (>50%) in the number of treatment applications required. Technology and procedures for using parasitoid species for seasonal inoculations were developed; field tests established that a complex of several species of parasitoids increased parasitism, reduced pest populations, and resulted in market acceptable cabbage and broccoli crops. The system was successfully validated in several fields of commercial cabbage in the Rio Grande Valley of Texas; a commercial insectary produced, sold, and released the beneficial insects. A commercial BC-IPM system that emphasizes augmentative releases of *Cotesia plutellae* Kurdjumov on several hundred ha of broccoli and cauliflower has been in operation in Guatemala and Mexico for the past three years. A program to manage *P. xylostella* and other crucifer pests has recently been initiated in Mauritius. The initial focus is on the development of a population database and construction of a facility for production of *P. xylostella* and *C. plutellae*. An evaluation and implementation phase will concentrate on the augmentative releases of *C. plutellae* and the judicious use of *B. thuringiensis*. A later phase of the program will utilize the combination of inherited sterility and releases of *C. plutellae* to manage DBM populations.

Key words: Diamondback moth; augmentation; parasitoids; management system

Introduction

During my career as a research scientist with the United States Department of Agriculture, Agricultural Research Service (Columbia, Missouri and Yakima, Washington, USA), we developed an alternative management system that utilizes augmentative releases of parasitoids and provides effective control of the complex of insect pests on cruciferous crops. The Biological Control-IPM System (BC-IPM) is environmentally sound and in grower use; it focuses on biological control, population monitoring and the inoculative releases of beneficial agents. The system replaces one that relies entirely on the routine application of chemical insecticides (Biever *et al.*, 1994).

It is increasingly difficult to find replacement insecticides for use in control of insect pests, thus we must develop alternate approaches to insect management. For most crop systems, research is focusing more on integrated pest management and an important component is biological control. Although biological control is often thought of, and developed as, a separate and distinct management approach, it should be the foundation of ecologically based systems of pest control which we call IPM. Regardless of the crop system, the process for developing the BC-IPM systems is similar and includes the following steps: (1) acquire fundamental biological information, (2) establish procedures for monitoring pest populations, (3) reduce the number of insecticide applications, (4) replace chemical pesticides with biological insecticides, and (5) maximize use of biological controls. Development of a BC-IPM system is usually slow and the degree of success is relative to the effort expended. The crucifer BC-IPM project was a 24 year process from initiation to commercial use and required several crisis situations to move it from the research plots to grower fields.

Bacillus thuringiensis – IPM program development

The goal of the program was to develop and implement a system which integrates a number of biological control agents and tactics into a comprehensive program to manage a complex of pests. It was the initial hypothesis that a management system that relied on the use of biological (microbial) insecticides rather than synthetic chemical insecticides would permit the survival of naturally occurring beneficial agents that, in turn would assist in reducing the pest populations. Also, we hypothesized that once a management system was established that minimized the need for synthetic chemical insecticides, we could further enhance suppression of the pests through early-season augmentative releases of selected beneficial agents. Appropriately timed, early-season, inoculative releases of beneficials should require relatively low numbers, because population densities of the pest species are usually lowest during their early generations each season, by introducing the beneficials into pest populations that are below economic levels, the beneficials should persist and increase in numbers if hosts are available throughout the growing season. Cabbage was selected as the test crop as it is an excellent challenge for biological control because several pests attack this crop every year, numerous applications of chemicals are applied routinely, and the final product the grower harvests must be free of insect damage. The process consisted of three phases of development: (1) research to replace chemical insecticides with biological insecticides, (2) implementation of phase one, and (3) seasonal inoculative releases of beneficial agents to maximize biological control.

The initial phase replaced chemical insecticides with the biological *Bacillus thuringiensis*. The system was based on regular field observations, knowledge of the relationships between host plants and pests, and understanding when and where to apply *B. thuringiensis*. To acquire the basic information we conducted population studies at an organic farm (Ferguson, St. Louis County, Missouri) during the 1967 growing season. This farm had not been exposed to any chemical pesticides for over 17 years, and the cabbage crop (1–1.5 ha annually), usually heavily damaged by lepidopteran pests, was far below market standards. Small plots, consisting of about 1,000 cabbage plants, (0.04 ha), were planted monthly (April to September) to provide a continuous supply of plant hosts for insect populations. The study plots, along with the grower's cabbage fields, were monitored every 3 days to collect population data on the imported cabbage worm (ICW) *Artogeia rapae* (L.) (Lepidoptera:Pieridae), the diamondback moth (DBM) *Plutella xylostella* (L.) (Lepidoptera:Yponomeutidae), the cabbage looper (CL) *Trichoplusia ni* (Hubner) and associated beneficial insects. ICW was the primary pest of spring cabbage grown at this location with populations at times exceeding 2 large larvae per plant; DBM was most abundant during the summer (over 4 per plant throughout July) and was at low levels the rest of the growing season; CL, considered the major pest of cabbage in the St. Louis area from late June through September, was not a pest at this farm during 1967 and, according to the grower never had been. Fewer than 10 CL larvae were observed throughout the entire season.

In 1967, *B. thuringiensis*, was a relatively new biological insecticide and was being used on a limited basis. We considered it to be the appropriate biological insecticide to incorporate into our management program; however, we were in need of field evaluation experience and data. After we thoroughly explained the use of *B. thuringiensis*, the grower permitted application to one of his cabbage fields. Good control was obtained with two applications of Thuricide 90 TS (5 liters/ha), one made against each of the two generations of ICW (first-instar). This produced a bumper crop and far more than his specialty market could absorb as he usually expected to lose about 50% of his crop. Insecticide resistance in CL was observed in 1967 and during 1968 and 1969 CL populations became unmanageable even though insecticides were applied every other day. Populations of large CL larvae reached 10–25 per plant and naturally occurring epizootics of nuclear polyhedrosis virus became the primary control. In 1968, cabbage insects and control practices were evaluated at several commercial vegetable farms in St. Louis County. Most growers were routinely making eight or more applications of synthetic chemical insecticides to their spring crop. We concentrated our efforts at one farm, hoping that management techniques developed at this farm would be disseminated by observation and word of mouth to the other growers in the area. Based on weekly monitoring of the spring cabbage, chemical pesticides were needed only twice, a 75% reduction over previous years. In 1969, only one application of *B. thuringiensis* was required. In 1970, based on observations made every other week at two truck farms, one grower harvested 50% of his cabbage crop without any treatments and the remainder of his crop required one application of *B. thuringiensis*. Another grower used one application of *B. thuringiensis* on the spring crop, and additional applications were made to the summer cabbage sprouts and fall cabbage crop at about three-week intervals. Thus, only six applications of *B. thuringiensis* were used for the seven-month growing season, versus approximately 20 applications of chemical insecticides in previous years. The cost per hectare for materials and labor for either chemical insecticides or *B. thuringiensis* was about $30. Thus, elimination of 14 applications provided a savings of $420 per hectare. We concluded that one or two timely applications of *B. thuringiensis* could protect the spring cabbage and probably not more than six or seven applications would be needed for the seven month growing season. This schedule represents a significant reduction in insecticide use and had no deleterious effects on cabbage production.

Ideally, *B. thuringiensis* should be used to keep populations of pests below given economically damaging levels and should avoid killing 100% of the pests. This allows for the continuous additive suppressive effects of the background beneficial populations to operate, thus reducing the number of applications of *B. thuringiensis* needed. During the development phase of the BC-IBM system, decisions on when to apply *B. thuringiensis* were based primarily on field experience and biological logic rather than on fixed threshold levels. During the 1971 season we conducted field studies to determine economic injury levels and established the following treatment levels: for transplants; treat when large (>7mm) larvae reach 0.3 per plant and when medium (3–7mm) and small (<3mm) larvae reach 1.0 per plant. After the eight-leaf stage, for the head area, treat when any large larvae are observed, and when 0.1 medium or small larvae are found; on the outer leaves treat when large larvae reach 1.0, medium 3.0, and small 6.0 per plant. Counts should be based on the examination of 20 plants per field. From 1970 to 1979 new chemical insecticides were available and most growers used them on a regular schedule. However, two growers on the *B. thuringiensis* system made approximately 1/3 the number of applications. In 1977 these two were the only growers that were able to control CL; insecticide resistance was developing and was a serious problem by 1979 (Wilkinson *et al.*, 1983). This provided an opportunity to implement the system that had been developed 10 years earlier.

B. thuringiensis program implementation

We initiated a program to implement the *B. thuringiensis*-IPM system in 1980. A three year plan was developed based on the judicious use of *B. thuringiensis* coupled with a scouting program. Year one focused on grower education with active participation by a few growers and the full cost of the scouting program was covered. In year two, the number of growers and acreage would increase and the growers would share the scouting costs. The primary goal of the year three, besides fine-tuning the program was to have the growers pay the full cost of scouting. In 1980 six growers participated with 25 ha of spring cabbage and 12 ha of fall cabbage. Each grower had 1–10 ha within two to six fields at each farm location. Insect populations were monitored weekly by a field scout; whole-plant examinations were made on 20 plants per field regardless of field size by walking a diagonal X transect and selecting plants at approximately uniform intervals. Applications were often restricted to certain fields or portions of specified fields; blanket treatments were seldom required. For the entire growing season of 1980, growers used about one-half as many applications of *B. thuringiensis* on their cabbage as they had of various chemicals during the 1979 season. During 1981 the program expanded to 54 ha and nine growers and in 1982 they had a total of 59 ha of cabbage, broccoli and cauliflower. Results in 1981 and 1982 were comparable to 1980.

Following the switch to the *B. thuringiensis*-IPM system there was an immediate decrease in the number of treatment applications required, and then during a 3–5 year period we saw a continued decrease in the number of *B. thuringiensis* applications. This occurred because there was an increase in background beneficial activity as the local agroecosystem stabilized. Following the 3-year program on education, demonstration, and implementation of the *B. thuringiensis*-IPM program, a private consultant took over the program.

Augmentation program – development

The next step to improving this management scheme required developing technology and procedures for adding beneficial agents through seasonal inoculations early in the crop season when pest populations were low. In 1986 we initiated this third phase; maximizing the use of biological control agents with focus on parasitoids. This phase was conducted at Yakima, Washington. Prior to initiation of this phase we carried out basic population studies to establish the database needed before initiating the field evaluation of beneficial species that would be part of the augmentation program. We focused on establishing this baseline information at several locations in Washington and Oregon (Biever 1992, Biever *et al.*, 1992) Existing laboratory facilities were modified and developed to accommodate a rearing area for production of the three host species and nine parasitoid species. Initial stocks of all but one parasitoid species were collected locally; *Cotesia plutellae* Kurdjumov was introduced from Hawaii. The three lepidopteran pest species, ICW, DBM, and CL, were reared using the same laboratory diet (Berger, 1963) for both colony production and to provide host material for parasitoids. Colonies of the following parasitoid species were established: *Diadegma insulare* (Cresson), *Oomyzus sokolowskii* (Kurdjumov), *C. plutellae*, *Microplitis plutellae Musebeck*, *Pteromalus puparum* (L.), *Phryxe vulgaris* (Fallen), *C. rebecula Marshall*, *Voria ruralis* (Fallen), and *C. marginiventris* (Cresson). In 1986 and 1987 we established colonies and developed rearing, production, and handling procedures for three pest and nine parasitoid species. From 1988 through 1990 we concentrated on evaluating and integrating a number of parasitoid species to regulate the pest complex with emphasis on population monitoring and early season inoculative releases of the parasitoids. In 1988 we conducted the first field releases of pests and parasitoids in isolated plots of cabbage; each plot consisted of 1,000 plants. The treatments were: pests only and two release rates of parasitoids (25 and 50 pairs per species per plot). We also developed handling, storing, and release techniques. In 1989 tests were conducted in isolated blocks of broccoli with seven species of parasitoids and we evaluated four treatments: pests only and parasitoids at three rates (150, 300, and 600 pairs/species/plot). Pest (adults) were released on all plots on 2 dates (17 days apart) at a rate of 250 pairs per species. Plots were separated by at least 1.6 k and consisted of 0.4 ha of broccoli. All three parasite rates reduced populations of the pest species. At harvest, plots with the two highest release rates had the least insect damage (less than 5%); and the control had the most damage (approximately 25%). Essentially, all broccoli heads from the release plots were marketable (U.S. Grade No. 1) because our ratings were conservative and considered the slightest damage that might have been caused by an insect. In 1990 we evaluated two treatments: pests only and pests plus two releases of nine species of parasitoids (70–400 pairs/0.4 ha/species). Plots with parasitoid releases had higher rates of parasitization (>80% by midseason) and reduced pest populations. We concluded that early season inoculations with parasitoids could reduce the number of applications of *B. thuringiensis* required and in some cases eliminate the need for *B. thuringiensis* applications.

Augmentation program-implementation

In 1990, a series of fortunate circumstances provided the opportunity for our BC-IPM program to move to commercial grower's fields. Buddy Madgen, owner and operator of BioFac, a commercial insectary in Mathis, Texas, was interested in developing a parasitoid release program for cabbage in the Rio Grande Valley of Texas as he saw an impending need for an alternative management approach. Growers had reached a crisis situation and could no longer effectively suppress populations of the DBM because of insecticide resistance. During the previous 6 years, cabbage production had declined significantly in the Rio Grande Valley primarily because of the inability to control DBM.

BioFac began parasite production and contracted with cabbage growers to participate in the biocontrol release program during the November 1990–April 1991 growing season. To support the program we conducted field-population monitoring of insect populations, information and assistance on rearing and release of beneficials, and documented the program under commercial field conditions.

The program BioFac implemented was a modification of the BC-IPM system we had developed, and was only concerned with two lepidopteran species, DBM and the CL. They released *C. plutellae*, and *D. insulare* for DBM, *C. marginiventris* and *Trichogramma pretiosum* Riley for CL, and the predator *Chrysoperla rufilabris* (Burmeister) for the lepidopterans, whiteflies, and aphids. DBM was expected to be the dominant pest; however, it turned out that the CL was the primary pest. This may have been a fortunate occurrence as it demonstrated to the growers and to BioFac the importance of a monitoring program to establish appropriate control tactics, particularly when these tactics are species specific. BioFac's program utilized regular releases of the beneficials, rather than tailoring them to scouting based decisions; thus, more beneficials were released than needed and, at times, releases were made when suitable host stages were not present. When implementing a new type of management strategy such as this, it is probably better to release too many rather than too few beneficials. Growers also are used to having insect management procedures applied on a regular basis; thus, scheduled releases provide them with a sense of security. Our premise was that if a scheduled release system could be cost effective and accepted by the growers, then the next step would be to release only when needed and, thus, reduce costs.

The program involved five growers and 53 ha of cabbage (eight fields) that were monitored weekly. Treatments were: release of beneficial agents only, release of beneficial agents plus *B. thuringiensis* when needed, and release of beneficial agents plus *B. thuringiensis* and chemical insecticides (fields put into the program after receiving one or more applications of chemical insecticides). Seventy-five percent of the fields that received releases of beneficial agents also received one application of *B. thuringiensis*. Cabbage fields not in the release program, but in the same geographical area, received between 5 and 26 applications of chemical insecticides. The cost of using the beneficials compared favorably with insecticide treated fields and provided satisfactory crop protection. Insect damage at harvest was evaluated at two grower locations. The average damage for fields treated with chemical insecticides was 1.4 % and for the BC-IPM fields it was 0.6 %. The average cost for the chemical insecticide treated fields was $390/ha and for the BC-IPM it was $395/ha. Although far from perfect, the field project demonstrated that a BC-IPM system that emphasizes augmentative releases of a number of beneficial species can regulate a complex of pest species.

A parasite release program utilizing *C. plutellae* for control of DBM has been in operation in Guatemala for three years and for two years in Mexico. Three to six releases of 500-1000 pairs/ha were made; rates depended on population pressures. BioFac initiated the program in Guatemala in October 1993 and through March 1994 more than 300 ha of broccoli and cauliflower were protected by this system. During the 1994–95 season the program included about 600 ha in Mexico and 250 ha in Guatemala. Releases were limited in 1996 as logistics of transporting the parasitoids from the USA to the other countries has become difficult and growers are often relying on routine applications of *B. thuringiensis,* thus we are already observing the reduced effectiveness of this biological insecticide in Mexico where many generations of DBM have been treated with *B. thuringiensis* during the last 9 years. In both Guatemala and Mexico a complex (different for each country) of lepidopteran pests occur at various times throughout the production season and these were effectively suppressed with timely applications of *B. thuringiensis* plus the native parasitoid populations. DBM is the primary pest of crucifers in Mauritius and is particularly damaging to cauliflower and cabbage. Insecticide resistance was first noted in the early 1980's and required the use of new replacement insecticides. In 1991 an integrated pest management program for DBM was initiated (S. I. Seewooruthun MOA, Reduit, Mauritius, unpublished data). Two parasitoid species, *C. plutellae* and *Diadegma semiclausum* Hellen, were introduced from the Asian Vegetable Research and Development Center, Taiwan in October 1991. Since the initial introduction, *C. plutellae* adults (over 9000) have been reared from field collected DBM larvae and released throughout the growing areas in Mauritius. *C. plutellae* is well established (parasitism is often 70–90%) in all crucifer production areas while *D. semiclausum* is rarely found (C. Dunhawoor, MOA, Reduit, Mauritius, unpublished data).

More recently a project has been initiated to utilize augmentative releases of parasitoids to suppress DBM populations as part of an overall program involving the release of sterile DBM. This program is being supported by IAEA, Vienna, Austria. During 1996 baseline population data is being collected from all production areas on pest and beneficial insects; a rearing facility for the production of DBM and parasitoids has been built, personnel have been trained for rearing on artificial diet and before the end of the year a series of demonstration/small field studies will be conducted. These fields will receive inoculative releases of *C. plutellae* and the judicious use of *B. thuringiensis* if needed. This product has not been used in Mauritius, thus if we initiate a program of grower use which is one of only making applications of *B. thuringiensis* when needed and as part of a BC-IPM system the resistance to *B. thuringiensis* should be avoided. Later phases of the program will include evaluation of the combination of inherited sterility and the inundative release of *C. plutellae.*

In developing specialized BC-IPM management programs it is important to remember that the systems are dynamic and under constant change and evolution, thus regular monitoring is essential. However, to be effective, grower education and acceptance are necessary along with the field monitoring and timely recommendations on control measures.

References

Berger, R. S. (1963). Laboratory techniques for rearing *Heliothis* species on artificial medium. USDA-ARS (Report) 33–84.

Biever, K. D. (1992). Distribution and occurrence of *Cotesia rubecula* (Hymenoptera:Braconidae), a parasite of *Artogeia rapae* in Washington and Oregon. *J. Econ. Entomol. 85:* 739–742.

Biever, K. D., R. L. Chauvin, G. L. Reed and R. C. Wilson (1992). Seasonal occurrence and abundance of lepidoptera pests and associated parasitoids on collards in the northwestern United States. *J. Entomol. Sci. 27:* 5–18.

Biever, K. D., D. L. Hostetter and J. R. Kern (1994). Evolution and implementation of a biological control-IPM system for crucifers: 24-year case history. *Amer. Entomol. 40:* 103–108.

Wilkinson, J. D., K. D. Biever, and D. L. Hostetter (1983). Resistance of the Cabbage Looper, *Trichoplusia ni* (Hubner) (Lepidoptera: Noctuidae) to Methomyl in Missouri. *J. Kans. Entomol. Soc. 56:* 59–61.