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# Integrating Pheromones into Vegetable Crop Production

*John T. Trumble*

## 1. Introduction

Vegetable growers historically have been cautious about adopting the use of new technologies. Their crops are frequently of high value and short duration and require exceptionally high cosmetic standards. As a result, unless there is a clear economic benefit, most producers are slow to incorporate new procedures; the adoption of pheromone-based technology for insect monitoring has been no exception. However, the use of pheromones in vegetables has been further inhibited by a series of recurring difficulties. Initially the user is faced with decisions regarding trap selection and placement, confusion over best pheromone dose for longevity, and a host of conflicting claims by industry representatives. Then there is the revelation that trap catches, more often than not, do not reflect larval populations in the field. Weather, stage of crop growth, and horticultural practices produce variable impacts on the reliability of pheromone trap data. Nontarget pests sometimes confound the trap collection information and even occasionally represent a health threat. Given these problems, the real surprise is that pheromones have now begun to achieve widespread use in commercial vegetable production for such diverse practices as documenting flight phenology, setting economic injury levels, and monitoring for pesticide resistance.

In a few cases, the mating-disruption technique has been employed successfully for control of vegetable crop pests. The use of this technique for control of *Keiferia lycopersicella*, the tomato pinworm, is probably the best documented. When integrated with the release of biological control agents and the judicious use of insect pathogens and pesticides with low mammalian toxicity, the mating disruption technique was shown to provide a significant reduction in *K. lycopersicella* populations and a clear economic benefit to tomato growers in Mexico. The experimental design, population data, and economic analyses of the project will be presented. The approach has also been widely used in California during the past 2 years.

There are many reasons for the relatively rapid acceptance of the mating disruption technique in tomatoes. Development of pesticide resistance and related loss of most effective chemicals are certainly important. Similarly, incorporating pheromones into a comprehensive integrated pest management program and demonstrating compatibility with biocontrol agents such as leafminer parasites, pinworm parasites and *Trichogramma* spp. was also of value. However, the single most important factor in grower acceptance was the evidence from a detailed cost–benefit analysis showing greater net profits from the program using pheromones as compared to the standard pesticide treatment approach.

This chapter is organized into two parts. The first part, Section 2, provides a brief history of the difficulties experienced by researchers and industry personnel in implementing pheromones for use as monitoring tools in vegetable crops. The second part, Sections 3 and 4, will focus on the use of pheromones specifically for monitoring and mating disruption of *K. lycopersicella*, the tomato pinworm.

## 2. Barriers to Acceptance of Pheromone Technology

Vegetable growers historically have been cautious about adopting the use of new technologies. Their crops are frequently of high value and short duration and require exceptionally high cosmetic standards. As a result, many growers suffer from what has been termed the "sleep at night syndrome" (terminology after B. Cartwright). That is, growers or their pest control advisors (PCAs) feel that if a pesticide has been sprayed, then they have done their jobs. If a catastrophic loss subsequently occurs, the loss was due to an "act of nature" and could therefore not be ascribed to their growing practices. In some developing countries, growers have the perception that implementation of IPM practices such as scouting or pheromone use are simply beyond their economic means or capabilities (Pollard 1991). Ironically, as pesticide resistance develops, this often means that growers spend more for less effective pesticide-based procedures.

The concerns just described have been alleviated to some extent by recent successes (see other chapters in this part) as well as the realization that pesticide availability is rapidly becoming limited. Expansion of the United State's urban population has led to an increase in the political influence of environmental activists, labor unions, and consumer groups which are increasingly adopting anti-pesticide agendas and sponsoring ballot initiatives designed to restrict pesticide use (Trumble 1990). Furthermore, fear of ground water pollution and concerns regarding cancer have stimulated a surge in legislation which further limit pesticides (Trumble 1989). These problems are exacerbated by the continuing trend for reduction in registration of new pesticides due to increased testing requirements and registration costs (Georghiou 1990). Thus, as growers become sensitized to the need to adopt new approaches to pest management, the opportunity exists for implementing the use of pheromones and other relatively new pest management technologies into commercial farming.

Nonetheless, even a brief discussion with growers regarding acceptance of any new arthropod control system will reveal several valid reasons for caution. New technologies are often flawed and require further study and modification before they become economically viable. Many growers have expensive pieces of equipment which promised to revolutionize pest control (electrostatic sprayers, tractor mounted insect vacuums, etc.) that are now rusting behind the barn. Juvenile hormones were promised to provide long-term control of most insect pests because these compounds were required by the insects for normal life processes. Despite the best guesses of researchers, resistance developed fairly rapidly to the "first-generation" products (Georghiou and Lagunes-Tejeda 1991), and many growers were caught by surprise when the products failed. Even with pheromones, much of the potential usefulness of the technology is only now being realized, some 20–30 years after the initial expectations following discovery (McNeil 1991).

### *2.1 Impediments to Application in Commercial Agriculture*

Like any new technology, pheromone use in vegetables suffered from incipient problems in application. One recurring difficulty has been the selection of the right trap, pheromone dispenser, dose, and field placement. Although this problem appears to be easily solved by simple comparative studies designed to measure best capture rates, grower acceptance of pheromone traps for monitoring is often based on ease of use and cost rather than effectiveness. As a result, species that can be collected in the inexpensive wing traps, delta traps, and bucket traps have been monitored more readily than those requiring omnidirectional traps or large cone traps (Sharma et al. 1973; Struble 1983; Mitchell et al. 1989). Over the past 10 years, numerous papers have been published on selection and efficiency of different trap designs and pheromone dosages (Trumble and Baker 1984; Gray et al. 1991; Valles et al. 1991; Jansson et al. 1992; see also the references in these articles). This diversity of trap designs and pheromone delivery systems, coupled with conflicting claims from manufacturers and less-than-ideal transfer of information from researchers to grower, may cause some PCAs or growers to avoid adopting an apparently confusing technology.

Researchers also have addressed related problems of trap saturation, pheromone longevity, convenience, placement, and nontarget captures (Proshold et al. 1986; Drapek et al. 1990; Campbell et al. 1992; Derrick et al. 1992). Even though most of these problems can be easily resolved through research, implementation of the modified methodology still can be difficult. Growers and PCAs are often reluctant to set up traps at specific heights if this makes finding the traps difficult or if poles or special stakes are required. The need for placing traps above the height of the canopy or between rows appears particularly onerous, because this can interfere with routine crop maintenance or pesticide application. Although some traps have proven quite efficient at collecting males attracted to pheromones, the lack of commercial availability, along with the time constraints on PCAs which limit their ability to manufacture the traps, has hampered implementation (Jansson et al. 1992). The inconvenience of sorting through related, nontarget moth species not only increases monitoring time, but makes identification difficult and may distort reports of trap captures (Adams et al. 1989; Weber and Ferro 1991). In some cases the attractancy of traps to nontarget insects may be more than just a nuisance. For example, cone-orifice traps designed and baited to catch *Spodoptera exigua* in tomato fields actually caught large numbers of bumble bees (*Bombus*), much to the distress of the people checking the traps (Trumble and Baker 1984; J. Trumble unpublished). Similar collections of stinging Hymenoptera have since been reported for other trap designs (Adams et al. 1989).

Perhaps the single most important factor which has limited the use of pheromone trapping for monitoring pests has been a lack of correlation between trap collections and egg or larval densities in the field; coefficients of determination in the range of 25–40% are common (Faccioli et al. 1993; Latheef et al. 1993; Witz et al. 1992). In some cases this relationship has been nonsignificant (Wiesenborn et al. 1988, *Helicoverpa zea* on sweet corn), while others have found no consistency in relationships (Campbell et al. 1992, *H. zea* on tomato). Efforts to improve correlations between *H. zea* trap catches and egg numbers in sweet corn have been almost heroic; researchers have evaluated a series of 1- to 2-hr time periods throughout the crepuscular/dark period of flight and found that selected time periods provided better relationships (up to $R^2 = 51\%$ for moths caught between between 4 and 5 A.M.) (Latheef et al. 1993). Unfortunately, while of considerable interest to researchers, the potential for implementation of this approach by PCAs and growers may be limited to those suffering from insomnia. In similar studies, researchers have found that relating trap collections to egg counts between minus 1 and +12 days following trapping could also improve the predictive value of relationships [Latheef et al. (1991) found correlation coefficients ($r$) ranging from 0.33 to 0.84; see also Weber and Ferro (1991)]. However this unpredictability of the delay variable makes implementation difficult if not impossible, and Weber and Ferro (1991) concluded that the pheromone traps might be most effective for timing egg searches.

A number of key factors probably have substantial influence on this relationship through effects on oviposition behavior, larval survival, or trap efficiency. For example, the stage of crop growth and availability of alternate hosts is of considerable importance for *H. zea* ovipositing in sweet corn (Wiesenborn et al. 1988). The presence of pesticide residues, the crop accession or variety grown, and so on, could also reasonably be expected to impact oviposition behavior or subsequent larval feeding behavior (Penman et al. 1988; Hoy et al. 1990). Pesticide residues in particular have been documented to change pest distributions (Trumble

1985), which would affect the relationship between trap catches and larval or egg population estimates. In some moths with wide geographic distributions, local regional "dialects" have been found which would affect responses to specific pheromone blends (Löfstedt et al. 1986b). Furthermore, a variety of weather conditions have been implicated as key factors influencing trap catches of males for many different systems (Dent and Pawar 1988; Elkinton and Cardé 1988; Jönsson and Anderbrant 1993; Pitcairn et al. 1990; Royer and McNeil 1993a). Because variations in weather conditions between years, crops, and locations are likely, and given that these factors can have differential effects on mortality and oviposition behavior, anticipating stable, predictive relationships between pheromone trap catches and larval or egg densities may be naive. In fact, the real surprise is that some pheromone-based monitoring programs have been remarkably successful in vegetables. This success is due, in part, to the tenacity of researchers who have overcome these obstacles to document reliable, efficient, and species-specific monitoring techniques employing pheromones.

## 3. Examples from the Literature

Although there are many creative ways that pheromones have been used for monitoring pest populations in vegetables, three basic approaches are most common. These approaches include employing pheromones to (1) document flight phenology, (2) set economic injury levels and (3) monitor for pesticide resistance.

### *3.1. Documenting Flight Phenology*

Information on flight phenology of pest insects is typically used in two ways. In many cases, the occurrence of a peak in flight activity can serve as a signal to initiate sampling procedures for eggs or larvae. This approach is currently suggested for *H. zea* infesting sweet corn in Massachusetts, USA (Weber and Ferro 1991) and strawberries in California, USA (Wiesenborn et al. 1988), as well as for the potato tuberworm, *Pthorimaea operculella*, infesting potatoes in Peru (Raman 1988).

A second common use for information on flight phenology is the documentation of migration patterns and overwintering habitats. Using pheromone trap collection data, Mitchell et al. (1989) were able to provide evidence that *Spodoptera frugiperda* migrations from endemic areas in the Caribbean to the U.S. mainland were not a critical component in annual reinfestations. Wiesenborn et al. (1988) used trap collections of *H. zea* in conjunction with weather data to suggest that the rare infestations of California strawberries were due to migrations resulting from the confluence of mild winters and a coastal counterclockwise low-pressure system called the "Catalina Eddy." Pheromone traps also were successfully used in conjunction with weather patterns to prove that *S. exigua* was overwintering in California, rather than migrating northward from Texas or Mexico (Trumble and Baker 1984).

### 3.2. Setting Economic Injury Levels

*P. operculella* is the target of one of the most geographically widespread control programs utilizing pheromones. This small gelechiid moth causes damage when larvae mine the leaves, stems, or exposed fruit of potatoes. Damage may occur both before and after harvest. Unlike most other systems, a useful predictive relationship often exists between pheromone trap catches and larval density in the foliage or percent fruit damage. This relationship has been used to establish threshold levels for treatment in Australia (Valencia 1981), India (Lal 1989), Peru (Raman 1982, 1988), and the United States (Shelton and Wyman 1979). Unfortunately, the authors note that changing the potato cultivar, the selection of pesticides used, irrigation schedules or practices, time of harvest, or even the soil type in which the potatoes are grown can dramatically alter the correlative relationship and render the technique less useful.

### 3.3 Monitoring for Pesticide Resistance

Riedl et al. (1985) and Haynes et al. (1986) pioneered the concept of using pheromone traps to monitor pesticide resistance in pest insects. The first work required that insects collected in traps be transported back to the laboratory for standard bioassays based on topical applications. The second eliminated the need for topical applications by incorporating the pesticide directly into the sticky material in the trap. The procedure of Haynes et al. (1986) was further developed by Brewer and Trumble (1989, 1991) to monitor the occurrence of pyrethroid resistance in *S. exigua* in tomatoes. This required the development of a considerable amount of background information including, a discriminating dose of fenvalerate in the sticker of pheromone traps (that is, a dose which will kill nearly all susceptible adults but few of the resistant moths) and information on the relationship between adult and larval resistance.

A sequential sampling plan based on the sequential probability ratio test then was constructed (Brewer and Trumble 1991). The technique allows populations to be rapidly categorized as highly resistant, moderately resistant, or susceptible with a high degree of reliability. This approach has yielded several substantial benefits including the following: (1) determination that probably field failure of the pesticide could be made prior to application, (2) sample sizes, and thus cost and effort, could be minimized, and (3) the rapidity of the test provided more timely information on resistance levels than the use of a topical application method. Such techniques may become increasingly important as the availability of pesticides declines. However, this approach has some substantial drawbacks such as the need for a large amount of developmental effort and the demonstration of a predictive relationship between insecticide resistance levels in the adult stage and larval stage of the pest species.

## 4. Monitoring and Mating Disruption of the Tomato Pinworm, *K. lycopersicella*

*K. lycopersicella* has been recognized as an important pest of tomatoes throughout much of North and Central America since its initial discovery in the Imperial Valley in California in 1923 (Oatman 1970; Charlton et al. 1991). Although some photosynthetic potential may be lost when larvae mine and fold the leaves, most economic damage occurs when larvae penetrate the fruit and become contaminants (Lin and Trumble 1983, 1985). Until the development of pheromones for this pest, control efforts had focused primarily on pesticides, because biological control agents, while present, did not provide an adequate level of control for commercial production (Oatman 1970; Oatman et al. 1979). Fortunately, following developmental studies in the 1970s and early 1980s, a commercial pheromone product became available. This product was a 96:4 *E:Z*-4-tridecenyl acetate blend (Jenkins et al. 1990). The development, refinement, and some applications of the pheromone have been described in detail by Jenkins et al. (1990) and Charlton et al. (1991) and will not be repeated here.

### *4.1. Initial Studies Using Pheromones for Controlling* K. lycopersicella

Beginning in the late 1970s through the 1980s, several attempts were made to use pheromones for control of *K. lycopersicella* in fresh market tomatoes. Results from the first studies were inconclusive (Jenkins et al. 1990). In the first replicated study, moth captures were reduced in plots of tomatoes in Florida that were treated with 40 g a.i./ha of pheromone, but no damaged fruit were found in either treatment. Unreplicated mating disruption studies in Mexico were encouraging, with a reduction in average percent fruit damage from 5.4% to 1.2%. However, because of the experimental design, statistical significance could not be determined.

A large-scale, 2-year study by Van Steenwyk and Oatman (1983) in southern California produced inconsistent results. In the first year, although significant reductions were seen in collections of adult moths in pheromone traps between treatments, there were no differences in foliage infestations or fruit infestations regardless of the level of pheromones applied (2.5, 10.0, or 40.0 g/ha). In a second year where only the 10.0 g/ha rate was used, significant reductions were reported in moth captures and for both larvae and mining injury in the foliage. However, differences in total fruit damage were not significant ($p < 0.05$ level), probably due to very low levels of fruit damage: 0.8% fruit damaged in the control versus 0.06% damage in the pheromone treatment. Unfortunately, the results of this study are confounded by the application of some unspecified pesticides for *S. exigua* control during both years that the authors conceded probably impacted *K. lycopersicella.*

In a related study, Van Steenwyk et al. (1983) developed a treatment threshold using pheromone traps. A pest density level of 10 moths/trap/night was suggested for initiating pesticide applications in California, based on a correlation coefficient of $r = 0.76$ between trap captures and fruit damage 2 weeks later. However, this relationship is only weakly predictive, and it could not be validated at other locations in California (Toscano et al. 1987). Levels of 10 or more moths/trap/night in Sinaloa are common (Alvarado-Rodriguez and Rivera-Rubio 1990; Trumble and Alvarado-Rodriguez 1993), and the threshold has not been adopted in Mexico. High levels of moth catches in Sinaloa are probably due to the presence of alternate hosts, abandoned fields, and volunteer tomatoes (Alvarado-Rodriguez and Rivera-Rubio 1990) as well as relatively high mean temperatures which do not fall below the thermal flight threshold of 11°C (Lin and Trumble 1985).

Jiménez et al. (1988) reported that the mating disruption technique was highly effective for *K. lycopersicella* suppression in cherry tomato production in northern California. In a 2-year study, peak fruit infestations ranged from 14% to 65% in plots treated 12 to 16 times with the broad-spectrum pesticides azinphosmethyl, methomyl, diazinon, or naled, whereas plots treated with pheromones only or pheromones and one application of *Bacillus thuringiensis* had infestations of only 1–5%. Unfortunately, no statistical analyses were conducted and significant differences between treatments could not be reported. Interestingly, the data suggested that some pesticide resistance may have developed to methomyl and/or diazinon because a field treated 16 times had 65% damage, whereas the completely untreated field had only 12% peak damage.

### *4.2. Mating Disruption in Commercial Tomatoes in Sinaloa, Mexico*

Studies on mating disruption of *K. lycopersicella* conducted in Mexico by Trumble and Alvarado-Rodriguez (1993) were initiated largely as a result of concern over development of pesticide resistance. In the 1970s and 1980s, *K. lycopersicella* developed resistance to a wide variety of pesticides in Mexico, and became a major pest of tomatoes (Brewer et al. 1993). Repeated applications of broad-spectrum insecticides applied to control the pest resulted in two major problems; residue levels of some exported fruit from Mexico were above U.S. tolerances (Food and Drug Administration 1979), and the pesticides were causing outbreaks of other pest species such as the leafminer, *Liriomyza sativae*. Throughout the 1980s, Mexico's 1 billion dollar tomato industry was in jeopardy; large populations of this pest were causing considerable economic hardship and some fields had to be abandoned prior to harvest (Alvarado-Rodriguez and Rivera-Rubio 1990).

By the late 1980s, it was evident that continuing with a control program for *K. lycopersicella* based solely on intensive pesticide use would probably result in rapid resistance development to any new pesticide and additional economic losses. At the request of the tomato growers in the State of Sinaloa, a series of experiments were designed and conducted to determine the feasibility of implementing an integrated control program based on mating disruption, parasite releases, an insect pathogen (*B. thuringiensis*), and abamectin, a pesticide with potential for *K. lycopersicella* control which was previously unused in Mexico and had low contact toxicity to mammals. The intent was to develop a program before abamectin became commercially available and thus could be used in a fashion that would maximize control while minimizing resistance development.

From the outset, several criteria for the program were agreed upon. First, because tomato production in Sinaloa is exceptionally labor-intensive, any control strategies chosen had to minimize human exposure to chemicals with high mammalian toxicity. Second, environmentally benign techniques would be given priority, because most of the runoff from this region feeds into the Gulf of California, which supports environmentally sensitive sport and commercial fisheries as well as vacation resorts. Finally, the program had to be economically viable. Without a clear indication that profits could be increased or at least maintained, there was little hope that the program would be commercially implemented. However, pheromone-based control alone could not provide a complete solution to the insect problems on tomatoes.

Sequential plantings in Sinaloa assure that migrations of *K. lycopersicella* from nearby abandoned or harvested fields could be anticipated. Developing (1) a larval treatment threshold (a density which would trigger controls other than mating disruption) and (2) a control technique which would not disrupt the biological control strategies for the other insect pests therefore was critical to the potential success of the program. Nearly concurrent studies by Wiesenborn et al. (1990) on the economics of insecticide treatment programs for tomatoes in California provided larval thresholds for treatment which could be modified for use in Sinaloa. Other IPM studies in California indicated that abamectin could provide substantial suppression of *K. lycopersicella* without causing significant increases in populations of *Liriomyza* species or killing adults of key hymenopterous leafminer parasites (Trumble 1990).

Minimal activity by abamectin against a complex of hymenopterous parasites attacking *L. sativae* suggested that abamectin would probably have little impact on release of the hymenopterous parasite, *Trichogramma pretiosum*, which was released for *H. zea* suppression. Release rates for this parasite were based on previous work by Elizondo-Alapisco and Alvarado-Rodriguez (1988). Similarly, *B. thuringiensis*, a pathogen specific to insects, was employed for control of *S. exigua* since this material has little or no demonstrated effect on parasites (Trumble 1990).

The experimental design and the economics of the IPM program have been reported (Trumble and Alvarado-Rodriguez 1993) and will not be repeated in detail here. However, additional results have been analyzed and a brief overview of the project will be necessary in order to interpret them. Following a series of preliminary studies to adjust thresholds and refine survey techniques, comparisons of insect populations, fruit damage, control costs, and net profits were made between a conventional insecticide treatment program (20–35 applications of two pesticides per application), an IPM program (mating disruption, *T. pretiosum* releases, as needed applications of *B. thuringiensis* or abamectin, etc.), and an untreated control. Each treatment was replicated (0.5 ha planting/treatment) in each of three valleys (Culiacan, Guasave, and Los Mochis) and in each of three seasons (fall, winter, and spring plantings, except for Culiacan, which was not planted in the spring). Thus, each treatment was evaluated on a total of eight 0.5-ha plantings. All plots were at least 1 km from each other and from commercial tomato fields. Mixtures of pheromones in hollow fibers and a flowable polybutene sticker (Ecogen, Inc.) were applied monthly at 13 g a.i./ha. Pheromones were applied at approximately 2-m intervals along every other row.

Data on *K. lycopersicella* were collected for males/trap/night (m/t/n), eggs/leaf, and larvae/plant. Adults were monitored at each plot with three wing-style traps. Larvae were counted on 10 randomly selected plants from each of row 1, row 5, and row 10 and from the center of the plots for 40 whole plant counts per week. Eggs were counted on 30 randomly selected leaves from the same field locations. Eggs were brought back to the laboratory and evaluated for percent parasitism. Data were pooled across locations and compared within plantings for each treatment using ANOVA and Fisher's Protected Least Significant Difference Test.

The mean number of m/t/n from the fall planting in Culiacan (Fig. 35.1A), the winter planting in Guasave (Fig. 35.1B), and the spring planting Los Mochis (Fig. 35.1C) show that populations of adults were generally high in all three growing seasons with most moths collected in the latter half of each season. The untreated control plots typically had the highest numbers collected, followed by the commercial treatments and then the IPM treatments. Although the corresponding larval counts per plant provided in Fig. 35.2 (A, B, and C) did show peak populations toward the end of the season, the population density increased by an order of magnitude with each consecutive planting. Thus, correlations between adult collections in traps and larval counts would not be reliable across plantings. Somewhat better correlations may have occurred within plantings, but predictive relationships were not evident and no effort was made to pursue adult trapping as a threshold treatment mechanism.

Information on the mean number of eggs per leaf and the mean percent parasitization of those eggs did show some interesting trends (Fig. 35.3). First, the egg density and percent egg parasitism increased in consecutive seasons as did the larval density. This may have occurred in part due to the greater availability of hosts. Second, there were significant treatment effects: Egg densities were different between the control and commercial treatments in the spring planting. Although the percentage of parasitized eggs was highest in the spring planting,

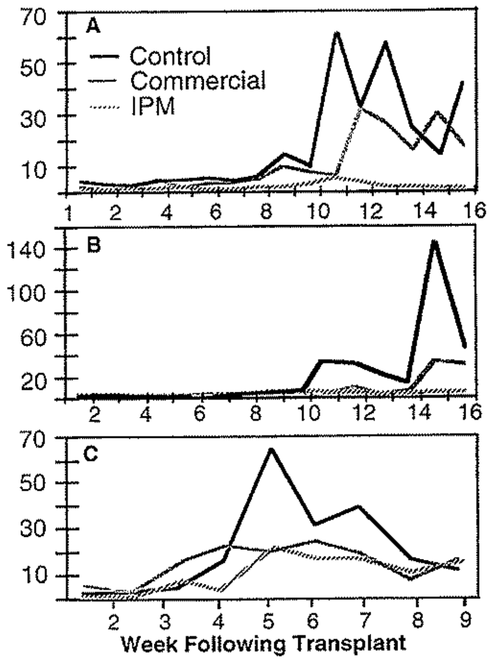

*Figure 35.1.* Mean number of *K. lycopersicella* males per pheromone trap per night in a fall planting in Culiacan (**A**), a winter planting in Guasave (**B**), and a spring planting in Los Mochis (**C**) valleys in the State of Sinaloa, Mexico. Comparisons are made between collections from tomato plantings treated with a commercial insecticide program, an IPM program, and an untreated control.

and there was a trend across plantings for higher parasitism in the IPM treatment, the commercial treatment was only significantly different from the IPM treatment in the winter planting. Nonetheless, such differences suggest that programs attempting to correlate egg counts with adult trap catches or larval densities should focus on viable eggs, because variable parasitism rates between treatments would add another confounding factor to the analysis.

In the fall planting, when *K. lycopersicella* larval populations were low, there were no differences in mean percent fruit damage between the commercial and IPM treatments (Fig. 35.4A). However, input costs of pesticides and pheromones were lower in the IPM program and net profits (value of the crop minus all production/harvest and sales costs) were correspondingly higher (Fig. 35.4B). The fruit damage in the winter and spring plantings was substantially higher than during the fall plantings, with commercial plots averaging significantly more damage (range 75–90%) than the IPM plots (range 33–35%). As a result, at the typical carton values of US $5 to $9, our commercial plots lost money (up to $1000/ha) in the winter and spring. However, even with these losses, a grower

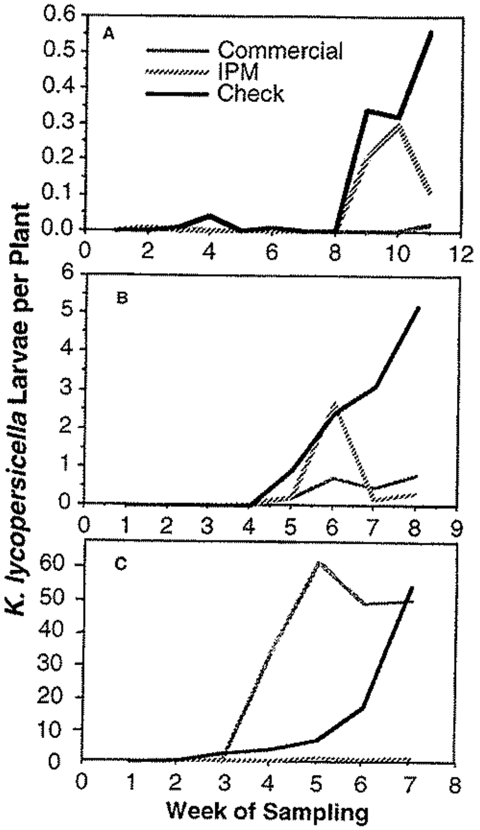

*Figure 35.2.* Mean *K. lycopersicella* larvae per plant in a fall planting in Culiacan (A), a winter planting in Guasave (**B**), and a spring planting in Los Mochis (**C**) valleys in the State of Sinaloa, Mexico. Comparisons are made between collections from tomato plantings treated with a commercial insecticide program, an IPM program, and an untreated control.

using the commercial program on 1000 ha and selling fruit at $9/carton would generate a net profit for the year (fall profits minus winter and spring losses) in excess of 1.5 million dollars. For the IPM approach at the same carton value profits were made in every planting, and the total net profit for the year exceeded 5 million dollars. Thus, a substantial economic incentive exists for using the IPM program.

The use of this IPM program meets the desires of the consumers for reduced pesticide usage. Furthermore, reduction in the potential for pesticide resistance development through the introduction of biological control agents as well as use of less pesticide allows growers a more sustainable option for long-term production of tomatoes. Finally, the substantial reduction in use of pesticides with

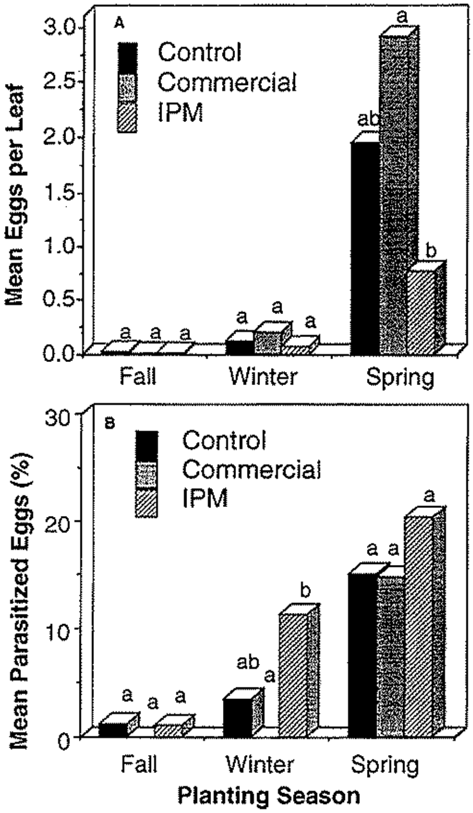

*Figure 35.3.* Mean eggs per leaf (**A**) and mean percent parasitized eggs (**B**) in fall, winter, and spring plantings in Sinaloa, Mexico. Letters above bars indicate significant differences within plantings at the $p < 0.05$ level, ANOVA, Fisher's Protected Least Significant Difference Test. Percent data were transformed by the arcsin square root transformation prior to analysis.

high levels of mammalian toxicity will help to minimize any potential human health concerns.

A caveat is in order. Given the extensive populations of *K. lycopersicella* presently in Sinaloa, along with the population isolation generated by growing tomatoes in geographically separated valleys, the possibility exists that behavioral adaptations or even physiological changes may occur which will reduce the effectiveness of the current pheromone formulation. Should a physiological resistance occur that results in change in pheromone blend, a simple modification in chemical composition might be adequate to deal with the problem. More than one blend may be required if the population is not homogeneous. However, development of a behavioral resistance (i.e., the adults move out of the field

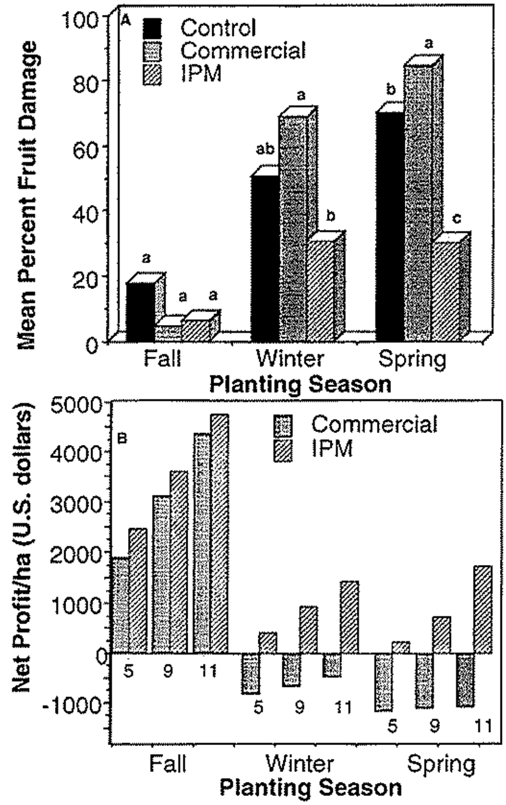

*Figure 35.4.* Mean percent fruit damage (**A**) and net profit information (**B**) for control, commercial, and IPM plantings in three seasons in Sinaloa, Mexico. Letters above bars indicate significant differences within plantings at the $p < 0.05$ level, ANOVA, Fisher's Protected Least Significant Difference Test. Percent data were transformed by the arcsin square root transformation prior to analysis. Numbers directly below bars in part B indicate prices for a standard carton of tomatoes.

to mate, etc.) may require additional biological studies to determine possible application strategies to alleviate the problem.

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