Agriculture, Ecosystems and Environment, 43 (1993) 267–284
Elsevier Science Publishers B.V., Amsterdam

Development and economic evaluation of an IPM program for fresh market tomato production in Mexico

John T. Trumble[a] and Benito Alvarado-Rodriguez[b]
[a]*Department of Entomology, University of California, Riverside, CA 92521, USA*
[b]*Agriculture Research Department, Campbell's-Sinalopasta, Apdo. Postal No. 185, Guasave, Sinaloa, 81000, Mexico*

(Accepted 22 July 1992)

ABSTRACT

Trumble, J.T. and Alvarado-Rodriguez, B., 1993. Development and economic evaluation of an IPM program for fresh market tomato production in Mexico. *Agric. Ecosystems Environ.*, 43: 267–284.

An integrated pest management (IPM) program based on intensive sampling, parasite releases, use of the mating disruption technique, and applications of microbial pesticides and abamectin was developed for the fresh market tomato industry in Sinaloa, Mexico. The IPM program for tomatoes was compared with conventional practices and an unmanaged control in each of three major agricultural valleys in autumn and winter crops, and in two valleys for spring plantings. The amount of marketable fruit production was similar for all treatments in the autumn plantings, but significantly higher in the IPM program during the winter and spring plantings. The densities of *Liriomyza sativae* Blanchard and *Keiferia lycopersicella* (Walsingham) eggs, larvae and adults were substantially reduced in the IPM treatment. Percent fruit damage by *Spodoptera exigua* (Hübner), *Heliocoverpa zea* (Boddie) and *Heliothis virescens* (Fabricius) was generally higher in the IPM treatment (4.2–10.9%) as compared with the conventional treatment (0.9–3.7%). However, the percent fruit damage by *K. lycopersicella* was significantly reduced in the IPM treatments (6.49–30.4%) vs. the conventional treatments (4.65–84.2%) in the winter and spring plantings. Net profits (value of fruit at harvest minus the cost of control) were substantially higher in the lower input IPM plots than in conventional treatments. In the autumn, net profits ranged from US\$304 to US\$579 ha^{-1} higher in the IPM treatment for carton values of US\$5–US\$11, respectively. In the winter and spring plantings, only the IPM approach was profitable. The IPM program offers substantial, long-term benefits in comparison with the conventional approach. Not only was the cost of the IPM program considerably less, but it: (1) reduced the potential for pesticide resistance development; (2) reduced the possibility of potential mammalian toxicity or non-target effects by using less toxic pesticides that are specific in activity; (3) provided less chance for fruit contamination or environmental damage.

Correspondence to: Professor John T. Trumble, Department of Entomology, University of California, Riverside, CA 92521, USA.

INTRODUCTION

The fresh market tomato industry in Sinaloa, Mexico, worth hundreds of millions of dollars annually (Buckley et al., 1986), was threatened during the 1980s by a complex of lepidopterous pests, including the tomato pinworm, *Keiferia lycopersicella* Walsingham, the tomato fruitworms *Heliocoverpa zea* and *Heliothis virescens*, and the beet armyworm, *Spodoptera exigua* (Alvarado-Rodriguez, 1988). Historically, these pests have been controlled with up to 40 applications per crop of multiple, broad-spectrum insecticides such as methomyl, permethrin and fenvalerate (Brewer et al., 1990). Not surprisingly, the extensive use of these insecticides has resulted in development of substantial resistance in the pest populations (Brewer and Trumble, 1991). Other serious problems also have occurred, such as the pesticide-induced appearance of secondary pests like the vegetable leafminers, *Liriomyza trifolii* (Burgess) and *Liriomyza sativae* Blanchard (Oatman and Kennedy, 1976; Johnson et al., 1980 a, b), adverse effects on key biocontrol agents (Oatman et al., 1983; Trumble, 1985), and excessive pesticide residue levels which have prevented export to the US (Anonymous, 1979). Therefore, an obvious need existed for the development and implementation of an IPM program that could offer a more sustainable approach to pest control and minimize the potential for environmental and human health concerns while maintaining or enhancing economic viability.

In spite of a low potential for environmental damage and a very low mammalian toxicity, control programs for conventionally produced tomatoes traditionally have not included the use of microbial pesticides or alternative strategies such as parasite release or mating disruption. Historically, this lack of effort to include *Bacillus thuringiensis* Berliner or related materials in control strategies was because of the perception that high value, short term crops were not as suitable as perennial crops for incorporating use of microbial pesticides (Biever and Hostetter, 1978). Similarly, releases of *Trichogramma pretiosum* Riley in tomatoes for fruitworm control, although generally efficacious (Oatman, 1988), were not widely accepted because of high cost, supply problems and ease of use of a prophylactic control program based on broad spectrum insecticides. Mating disruption techniques, while successful in controlling *K. lycopersicella* on cherry tomatoes, have had mixed success in fresh market tomatoes (Van Steenwyk and Oatman, 1983; Jenkins et al., 1990).

One of the best methods for influencing the growing practices for vegetable production is to provide a complete management approach for the pest complex rather than a short-term solution to a single pest problem (Trumble, 1990). This approach has at least two advantages. First, techniques to control resistance development can be incorporated. Second, a complete management system allows the development of low or reduced pesticide input programs which can be analyzed using available economic techniques for comparison with commercial practices. Therefore, the primary objectives of the studies reported here were to develop and evaluate an IPM program for use in Mexico's fresh market tomato industry.

MATERIALS AND METHODS

Fresh market tomatoes are grown in the Culiacan, Guasave and Los Mochis Valleys of Sinaloa, Mexico. The region uses three discrete plantings; autumn (October–December), winter (November–February) and spring (January–May). Following a series of pilot studies in the spring of 1988, three, ½ ha plots were established in 1988–1989 for each of the planting dates within each of the three valleys with the exception of Culiacan, where the spring planting was lost because of a misunderstanding resulting in poor agronomic practices. Each ½ ha plot was at least 1 km from the others in each site in order to avoid interference between techniques. Selection of a treatment program for each plot was made randomly. Within each planting, each site was considered a replicate.

Three treatments were tested concurrently in each valley. The first was a conventional treatment, consisting of multiple applications (see Tables 1–3) of two broad spectrum pesticides, methamidophos (Tameron®, Bayer, Bayerwerk, Germany) at 1.0 l $\mathrm{ha^{-1}}$ and permethrin (Pounce®, FMC, Philadel-

TABLE 1

Control costs (US$) for fresh market tomato production in Culiacan

Treatment	No. applications	Cost per application $\mathrm{ha^{-1}}$	Total cost
Autumn planting			
Conventional	35	35.30	1235.50
IPM			
Endosulfan	1	19.80	19.80
Avermectin	3	80.40	241.20
Trichogramma	9	2.30	20.70
Pheromones	3	76.80	230.40
B. thuringiensis	2	17.00	34.00
			Total 546.10
Winter planting			
Conventional	35	35.30	1235.50
IPM			
Endosulfan	3	19.80	59.40
Avermectin	2	80.40	160.80
Pheromones	3	76.80	230.40
Trichogramma	4	2.30	9.20
B. thuringiensis	3	17.00	51.00
			Total 510.80

TABLE 2

Control costs (US$) for fresh market tomato production in Guasave

Treatment	No. applications	Cost per application ha^{-1}	Total cost
Autumn planting			
Conventional	35	35.30	1235.50
IPM			
Avermectin	1	80.40	80.40
Pheromones	3	76.80	230.40
Trichogramma	9	2.30	20.70
B. thuringiensis	1	17.00	17.00
			Total 348.50
Winter planting			
Conventional	35	35.30	1235.50
IPM			
Avermectin	5	80.40	402.00
Pheromones	4	76.80	306.00
Trichogramma	8	2.30	18.40
B. thuringiensis	9	17.00	153.00
			Total 879.40
Spring planting			
Conventional	35	35.30	1235.50
IPM			
Avermectin	8	80.40	643.20
Pheromones	4	79.80	306.00
Trichogramma	5	2.30	11.50
B. thuringiensis	5	17.00	85.00
			Total 1045.70

phia, PA) at 0.5 l ha^{-1}. Every attempt was made to follow application programs used by the commercial fresh market tomato industry in each valley, but numbers of applications vary between growers and numbers of compounds included in each tank mix are similarly variable. Growers that spray less frequently may use more chemical in each application. Thus, the conventional treatment represents the best approximation in both efforts and costs of an average control program. Sprays were applied with a backpack sprayer following local commercial practices.

The second treatment was designed as a lower input IPM system. This treatment included mass releases of *T. pretiosum* for fruitworm suppression, which have proved successful on processing tomatoes in the area (Elizondo-Alapisco and Alvarado-Rodriguez, 1988). Five to nine releases of 100 000 *T. pretiosum* per release were made on each plot. The parasites were provided as pupae within *Sitotroga* sp. eggs glued on small cards, and these cards were

TABLE 3

Control costs (US$) for fresh market tomato production in Los Mochis

Treatment	No. applications	Cost per application ha^{-1}	Total cost
Autumn planting			
Conventional	35	35.30	1235.50
IPM			
Avermectin	2	80.40	160.80
Pheromones	3	76.80	230.40
B. thuringiensis	1	17.00	17.00
Trichogramma	9	2.30	20.70
			Total 428.90
Winter planting			
Conventional	35	35.30	1235.50
IPM			
Endosulfan	1	19.80	19.80
Avermectin	8	80.40	643.20
Pheromones	4	76.80	306.00
Trichogramma	8	2.30	18.40
B. thuringiensis	8	17.00	136.00
			Total 1123.40
Spring planting			
Conventional	35	35.30	1235.50
IPM			
Avermectin	8	80.40	643.20
Pheromones	3	76.80	230.40
Trichogramma	5	2.30	11.50
B. thuringiensis	7	17.00	119.00
			Total 1004.10

clipped to foliage systematically throughout the plot. *B. thuringiensis* (Javelin®, Sandoz Chemical, Palo Alto, CA) was applied at 2.4 l ha^{-1} when *S. exigua* populations exceeded a threshold of one larvae per four plants. The mating disruption technique (pheromones from Scentry, Buckeye, AZ) consisted of monthly applications of pheromones in hollow fibers mixed in a flowable polybutene adhesive. Fiber/adhesive mixtures were applied at approximately 2 m intervals along every other row with a wooden stick to transfer a small amount of mixture. The application rate was 13 g a.i. ha^{-1}. Abamectin application (Agrimec®, Merck and Co., Rahway, NJ) at 0.0135 kg a.i. ha^{-1} was made when *K. lycopersicella* larvae exceeded the threshold of three to four larvae per 3 m of row (0.25 per plant) (modified from Wiesenborn et al., 1990). In addition, up to three applications of endosulfan (Hoechst AG, Frankfurt, Germany, 35%, 1.5 l ha^{-1}) were needed (Tables 1–3) in some plots to help control outbreaks of the potato aphid, *Macrosiphon euphorbiae* (Thomas).

The third treatment was an untreated control. As with all plots, the controls were grown using local, horticultural practices including trellising. Plants were grown 0.5 m apart in rows with 1.5 m centers.

Insect population assessment

Insect populations were monitored in all treatments and locations weekly. The leafminer population was assessed acording to the methodology of Johnson et al. (1980), and consisted of using ten pupal trays per plot. *S. exigua* larval populations were assessed by inspecting 60 tomato plants randomly selected on a diagonal transect within each experimental plot. *K. lycopersicella* adults were monitored using three wing style pheromone traps (Wyman, 1979) per treatment per valley as described by Toscano et al. (1987). Egg densities were determined by randomly sampling 30 leaves in rows 1, 5 and 10 for each side of the experimental plot as well as an additional sample from the center of the field. The larval population of tomato pinworm in foliage was monitored by inspecting ten whole plants randomly selected from each of rows 1, 5 and 10 from each side of the experimental plot as well as a sample from the center of the field. Data were pooled within plantings for analysis of variance (ANOVA) and, if significant at the $P < 0.05$ level, followed by means separation with Fisher's Protected Least Significant Difference (PLSD) test (Fisher, 1949). All analyses were conducted using Super ANOVA (Abacus Concepts, Berkeley, CA).

Marketable fruit production

Plants were harvested from 10 m sections of rows 1, 5 and 10 for each side of the experimental plot as well as an additional sample from 30 m of row from five rows in the center of the field. All orange and red fruit were harvested. Plots were harvested as long as fruit production continued (up to four times per plot). All fruit was counted and weighed. This approach avoided the underestimation of yield problems that occur when only percent fruit damage is assessed (Welter et al., 1989). Percent fruit damage assessment for tomato fruitworms and *S. exigua* consisted of inspecting 100 randomly collected fruit in each experimental plot; fruit losses were evaluated together for these insects because of difficulty in separating feeding damage by species when infestations are high. *K. lycopersicella* damage was monitored by inspecting 50 randomly sampled fruit each from rows 1, 5 and 10 for each side of each experimental plot and a sample of 50 fruit from five rows in the center of the field (a total of 650 fruit per plot). For all damage estimates, the number of fruit were weighted by the damage level on each harvest date to generate a seasonal average for fruit damage by treatment. All percentage data were transformed by an arcsine square root transformation, analyzed by ANOVA and, if *F* values were significant at the $P<0.05$ level, followed by means separation with Fisher's PLSD test.

Economic analyses

Production costs associated with pesticide application, and pesticide purchase were supplied by growers, agricultural chemical companies and related chemical supply warehouses. Discussions with growers indicated that the range of applications was from 20 to 45+ per crop, usually with multiple pesticides per application. The numbers of conventional applications therefore were standardized for comparative purposes in the economic analyses at 35 per crop of two pesticides. Prices for pheromones, traps and adhesive were provided by a commercial pheromone production company (Scentry, Inc., Buckeye, AZ) and several growers. Prices for all products tended to vary with the amount of purchase, so for purposes of comparison, all costs were standardized for an average-sized farm (500–1500 ha) at the levels shown in Tables 1–3. A partial budget analysis was used. Gross profits were calculated by determining the weight of marketable fruit produced per hectare using average fruit weight per 10 m of row for each planting and location (see previous section for sampling plan), dividing by 11.35 kg (the weight of fruit in a standard carton), and then multiplying the number of cartons by the dollar value per carton. The net profit is defined as the value of fruit at harvest minus the cost of control; this is not a true net profit as the horticultural costs (planting, labor, harvest, etc.) were not included. However, because each grower permanently employs a large field crew, such costs are static and vary little with insect control strategy.

RESULTS

Insect population assessment

Liriomyza sativae populations were substantially different among treatments in the winter and spring crops (Table 4). The conventional treatment consistently averaged higher numbers of pupae per tray day^{-1} than the IPM and control treatments, where *Liriomyza* populations remained steadily low throughout the growing season. Although the tomato plant can withstand considerable foliar damage without yield loss (Pastemak et al., 1979), levels observed in the conventional plots probably caused significant effects on fruit yield and size. J. Trumble and E.R. Oatman (unpublished data, 1984) found significant fruit size reductions in California when populations reached 20 pupae per tray day^{-1}.

The exceptionally high leafminer populations in the conventional treatment were probably a result of the adverse pesticidal effects on the leafminer

TABLE 4

Populations of immatures of leafminers and eggs of *K. lycopersicella* and percent fruit damage by lepidopterous pests for commercial, IPM and control programs

Treatment and season	*Liriomyza* spp. per tray day^{-1}	*K. lycopersicella* eggs per leaf	Mean % fruit damage[1]	
			S. exigua+ fruitworms[2]	*K. lycopersicella*
Autumn planting				
Control	66.0a	0.030a	13.0b	17.56a
Conventional	73.3a	0.007a	1.4b	4.65a
IPM	57.8a	0.008a	10.9b	6.49a
Winter planting				
Control	31.4a	0.12a	17.3a	50.7ab
Conventional	152.9b	0.20a	3.7a	68.5b
IPM	44.6a	0.07a	9.9a	30.4a
Spring planting[3]				
Control	10.5b	1.95ab	11.1b	69.7b
Conventional	185.1a	2.92a	0.9a	84.2a
IPM	4.1b	0.77b	4.2a	30.2c

[1] Arcsine transformation followed by ANOVA and means separation by Fisher's Protected LSD; data back transformed for presentation; means followed by the same letter are not significantly different at the 0.05 level.

[2] Fruitworms include *Heliocoverpa zea* and *Heliothis virescens.*

[3] Based on plots in Guasave and Los Mochis Valleys only.

parasites (Oatman and Kennedy, 1976). Similar results have been reported for pesticide use in other crops (Trumble, 1990). The low leafminer populations in the IPM treatment probably arose from a combination of the control provided by avermectin and the impact of the parasite populations. Although the avermectin was intended as a control agent for *K. lycopersicella*, this compound effectively controls *Liriomyza* spp. leafminers with little or no impact on their associated parasites (Trumble, 1985). The lack of differences in leafminer densities in the autumn planting is difficult to explain. It is possible that the parasite population required much of this period to reach levels needed to provide adequate leafminer suppression.

Spodoptera exigua larval populations in the autumn crop followed similar trends in all treatments, and were not significantly different (mean range, 0.003–0.054 larvae per plant, $F=0.631$, d.f.$=2,6$, $P=0.564$). Similar trends were documented in the winter (mean range, 0.08–1.36 larvae per plant, $F=0.889$, d.f.$=2,6$, $P=0.459$) and spring plantings (mean range, 0.18–0.56 larvae per plant, $F=0.508$, d.f.$=2,3$, $P=0.646$). Difficulty in locating the negatively phototactic late instar larvae (Griswold and Trumble, 1985) probably accounted for the lack of statistical separation between treatments by increasing the variance in the samples.

K. lycopersicella adult catches in pheromone traps were considerably reduced in the IPM treatment (Fig. 1). The economic threshold level of five moths per trap per night was only occasionally exceeded. In contrast, pheromone traps in the conventional and control treatments routinely surpassed the threshold, reaching a high of 67 moths per trap per night in the spring planting in Los Mochis and 143 moths per trap per night in the winter planting in Guasave, respectively.

Populations of *K. lycopersicella* immatures were lowest in the autumn and highest in the spring planting. Significant differences between treatments in eggs per leaf could be detected only for the spring planting, where the IPM treatment exhibited the lowest egg density ($F = 12.361$, d.f. $= 2,3$, $P = 0.036$) (Table 4). Larval populations increased from a maximum of 1.5 per plant in the autumn to 5.6 per plant in the winter crop and over 70 per plant in the spring (Fig. 2). In the winter planting, when *K. lycopersicella* larval densities became economically important, the IPM program provided control generally equivalent to the conventional practices. Both of these approaches resulted in fewer larvae per plant than the control. Larval densities in the IPM

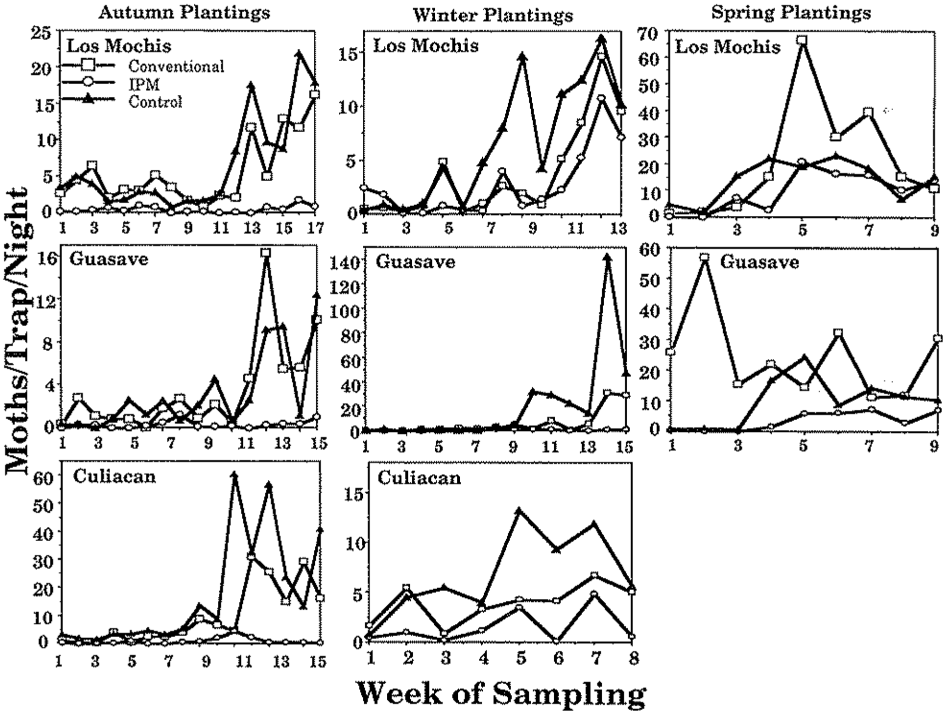

Fig. 1. Mean *K. lycopersicella* moths per trap per night collected in commercial, IPM and control treatments for autumn, winter and spring tomato crops in Sinaloa. Sample sizes and replicate locations are listed in the methods section.

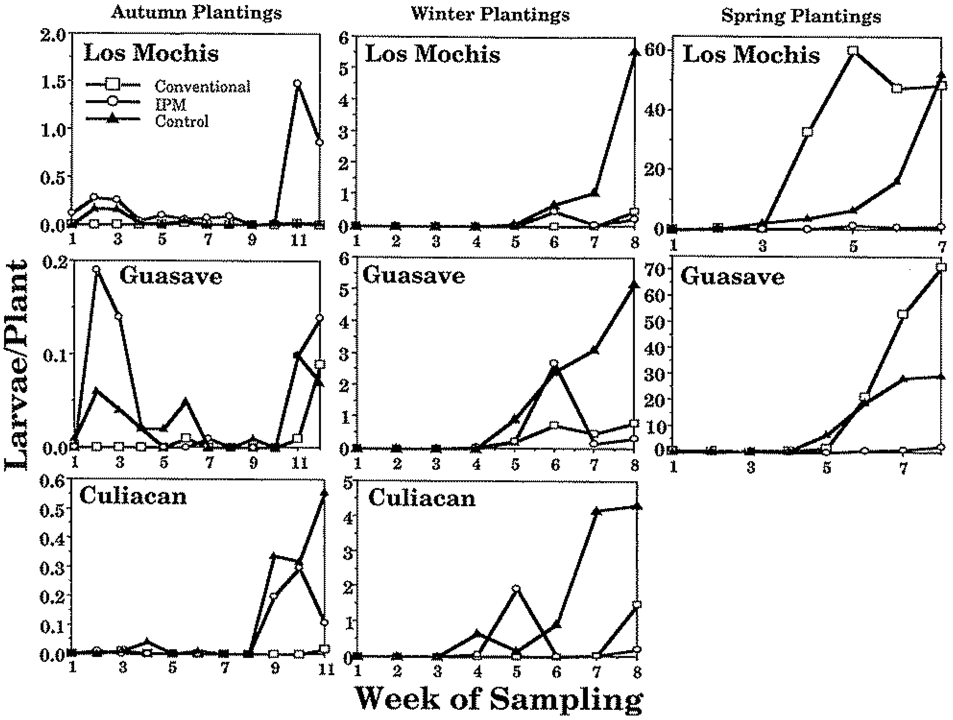

Fig. 2. Mean *K. lycopersicella* larvae per plant in commercial, IPM and control treatments for autumn, winter and spring tomato crops in Sinaloa. Sample sizes and replicate locations are listed in the methods section.

treatments were dramatically less in the spring plantings in Los Mochis and Guasave, where the conventional and control treatments exceeded 30 larvae per plant during the harvest period (Fig. 2). Analysis of data on percent parasitism of *K. lycopersicella* eggs and larvae suggested that the generally higher levels of *K. lycopersicella* larvae in the conventional as compared with the control treatment were probably owing to undesirable pesticidal effects on biological control agents (B. Alvarado-Rodriguez and J.T. Trumble, unpublished data, 1990).

Marketable fruit production

Marketable fruit production varied between plantings and treatments (Fig. 3A). The most marketable fruit was produced in the autumn, and the least in the spring. The growers in the region suggested that this represented a typical pattern of production, which they ascribed in part to a physiological effect of the cooler temperatures occurring in winter and spring in Sinaloa. Treatment differences were significant in the winter and spring plantings, when the IPM

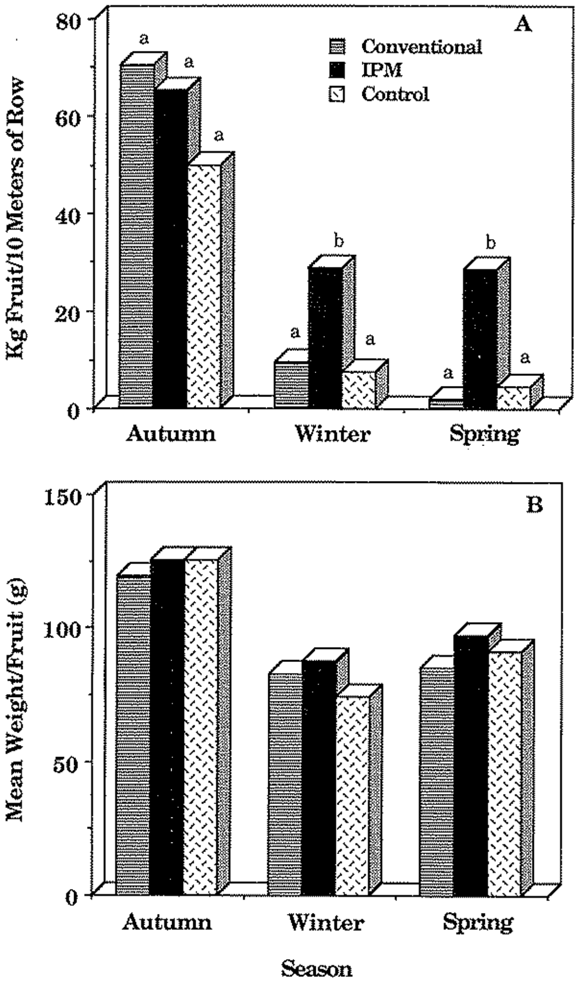

Fig. 3. Mean marketable fruit per 10 m of row (A) and mean fruit weight (B) produced in commercial, IPM and control treatments for autumn, winter and spring tomato crops in Sinaloa. Sample sizes and replicate locations are listed in the methods section. Letters above bars in A refer to means separation by Fisher's PLSD test.

treatments produced significantly more fruit than the conventional or control treatments (winter, $F=5.372$, d.f.$=2,6$, $P=0.046$; spring, $F=9.590$, d.f.$=2,3$, $P=0.049$). Most of this improvement came from the improved control of the tomato pinworm in the IPM system (Table 4). Damage levels were over twice as high in the control and conventional treatments as in the IPM treatments. The combination of avermectin and pheromones in the IPM treatment did not provide complete control and improvements are needed, but the results were far superior to the standard chemical control procedures. Clearly, even repeated applications of the two pesticides utilized in the conventional treatment did not provide significant control of this pest in comparison with the control.

The autumn planting produced the largest average fruit weight (Fig. 3B). Within each treatment, there were significant differences in average fruit weight between the autumn planting and either the winter or spring plantings (conventional treatment, $F=24.008$, d.f.$=2.5$, $P=0.003$; IPM treatment, $F=12.248$, d.f.$=2,5$, $P=0.012$; control treatment, $F=11.140$, d.f.$=2,5$, $P=0.014$); winter and spring plantings did not differ. In addition, the mean weight per fruit was not significantly different among treatments (Fig. 3B). Although the average fruit weights were not significantly different, the proportion of the fruit which could be packed into a larger size class was not determined. A weight increase averaging 12 g per fruit in the IPM treatment as compared with the conventional treatment for the spring planting may have increased the proportion of larger fruit, which usually wholesale for US$1–US$2 more per carton. Because we did not collect size class data, potentially increased revenues for the IPM treatments from sale of a larger sized fruit were not included in the economic analyses.

Fruit damage from *S. exigua, Heliocoverpa zea* and *Heliothis virescens* was significantly greater in the IPM treatments compared with the conventional treatments in the autumn and spring plantings (autumn, $F=14.588$, d.f.$=2, 6$, $P=0.005$; spring, $F=26.590$, d.f.$=2,3$, $P=0.012$) (Table 4). Results from applications of *B. thuringiensis* were not significantly different from damage levels in the control treatments in autumn and winter plantings, but damage was significantly reduced in the spring crop (Table 4).

Economic analyses

The lower input IPM program was substantially more cost effective than the conventional approach. The cost of the IPM program was equivalent to less than 20 applications (two pesticides per application). Costs for control in the IPM treatments were generally lowest in the autumn planting, when insect population pressures were less, and highest in the winter and spring crops when *K. lycopersicella* populations reached maximum levels (Tables 1–3). Despite numerically lower amounts of marketable fruit in the IPM vs. the conventional treatment in the autumn crop, net profits (value of fruit at harvest minus the cost of control) ranged from US$304 to US$579 ha^{-1} higher in the IPM treatment than in conventional treatment for typical market values of US$5–US$11 per carton (Fig. 4). This difference resulted from the substantially reduced control costs in the IPM treatments. Although the analyses were standardized at 35 applications for each crop, growers may use fewer applications during the autumn planting than in the winter and spring (B. Alvarado-Rodriguez, personal communication, 1990). This practice serves

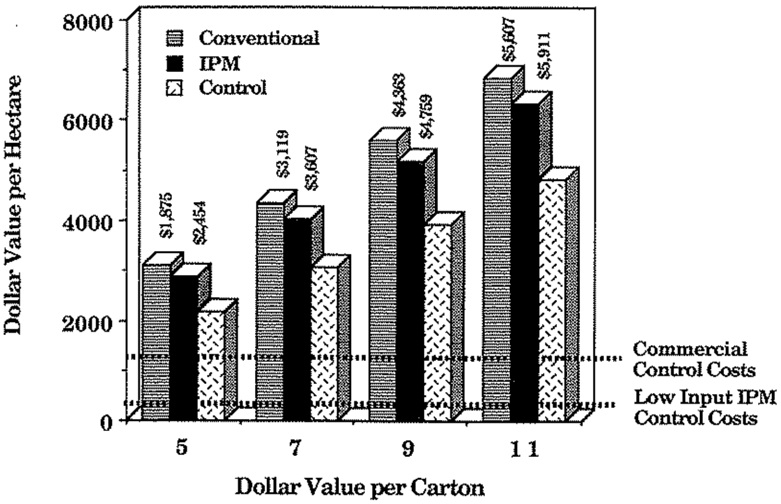

Fig. 4. Net profit analysis from the autumn planting in Sinaloa. The height of the bars indicates the value of the crop as the market value (dollar value of the cartòns) changes. The dotted lines show the cost of the commercial and the IPM control strategies. The net profits (value of the crop minus the cost of pest control) are shown directly above the commercial and IPM bars.

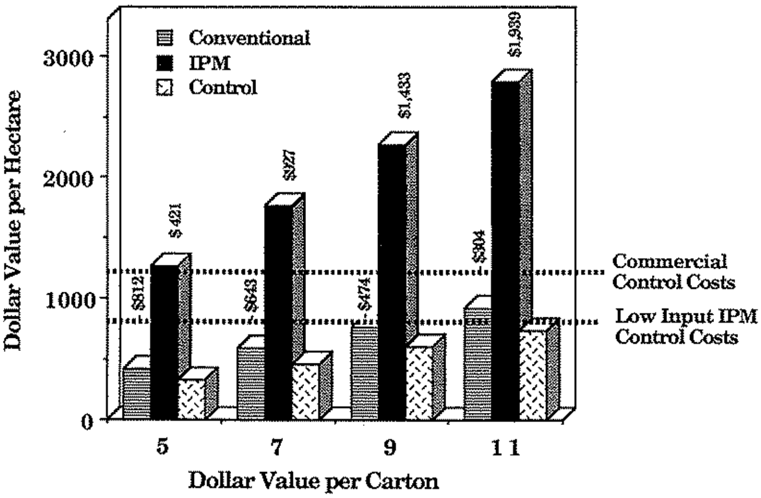

Fig. 5. Net profit analysis from the winter planting in Sinaloa. The height of the bars indicates the value of the crop as the market value (dollar value of the cartons) changes. The dotted lines show the cost of the commercial and the IPM control strategies. The net profits (value of the crop minus the cost of pest control) are shown directly above the commercial and IPM bars.

to reduce the net profit differential between the IPM and conventional treatments, assuming damage in the conventional treatments was not increased.

In the winter and spring plantings (Figs. 5 and 6), the differences in net

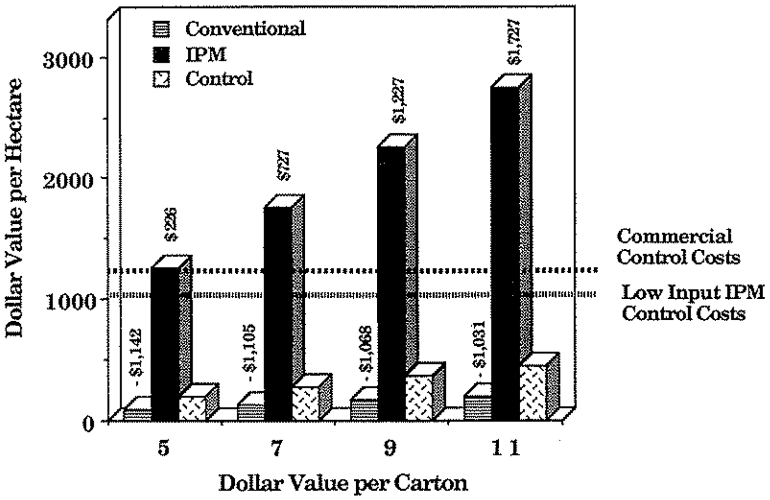

Fig. 6. Net profit analysis from the spring planting in Sinaloa. The height of the bars indicates the value of the crop as the market value (dollar value of the cartons) changes. The dotted lines show the cost of the commercial and the IPM control strategies. The net profits (value of the crop minus the cost of pest control) are shown directly above the commercial and IPM bars.

profits were greater. In fact, in the experimental plots, only the IPM approach was profitable. The combination of reduced pest control costs and increased fruit production resulted in a net profit differential between the conventional and IPM treatments ranging from US$1233 to US$2243 in the winter planting and US$1368 to US$2758 in the spring crop for US$5–US$11 per carton markets.

DISCUSSION

The IPM program documented in this study is probably not in its most efficient form because it was designed conservatively. This approach was necessary because it has been the authors' experience that persuading growers to risk profits on a program which has previously failed is a difficult proposition; growers of relatively short term, high value crops such as vegetables tend to be conservative when considering pest control. Additionally, because the low cost of field labor allowed substantial efforts for sampling purposes, sampling plans used to assess insect populations in the IPM program were designed to provide information on insect dispersion as well as simple population intensity. Therefore, the use of more efficient stratified or sequential sampling plans for some of the insects (Zehnder and Trumble, 1985; Shelton and Trumble, 1990) could increase the efficiency and economic viability of the IPM program.

Documenting the cost effectiveness of each of the components of the IPM program was not possible given the data collection methods. However, conclusions can be drawn regarding the usefulness of the mating disruption technique and the application of *B. thuringiensis*, two practices which have historically generated variable results (Biever and Hostetter, 1978; Silverstein, 1990; Baker et al., 1990). The mating disruption technique used in the IPM treatments consistently resulted in the fewest captures of *K. lycopersicella* adults of all the treatments (Fig. 1). Unfortunately, such reductions in adult collections do not ensure reduced fruit damage (Van Steenwyk and Oatman, 1983). However, both egg densities (Table 4) and larval populations (Fig. 2) in the IPM treatments were reduced in comparison with the conventional program, particularly during the spring planting when *K. lycopersicella* densities were at maximum. Although some of the larval mortality was almost certainly because of the effects of abamectin application, this compound is not ovicidal and has not been implicated as an oviposition deterrent (R. Brown, personal communication, 1991). Thus, given that the research plantings were relatively small (2 ha per valley) and subject to exposure to immigration of previously mated female moths, the apparent success of this approach on a limited scale suggests that the technique would likely be more effective as the treated acreage increases (Rothschild, 1981).

Bacillus thuringiensis was useful in the IPM program because it does not kill the key parasite species which control *Liriomyza* species, it is non-toxic to humans and environmentally safe (Trumble, 1990), and helps reduce the fruit damage by lepidopterous pests. A range of *B. thuringiensis* isolates and formulations have recently shown improved efficacy for *S. exigua* suppression (Moar and Trumble, 1990). As such new products achieve registration, their incorporation into the IPM program will improve the economic viability of this approach.

The effective implementation of the IPM program in Sinaloa faced some major constraints. Because tomatoes represent an important balance-of-trade item with the US (Buckley et al., 1986; Ramirez Diaz, 1988), and because the fresh market tomato industry is a major employer in the region, the industry is often subsidized by the Mexican government. The IPM program therefore had to produce at least as much fruit as current practices and employ as many people. By reassigning some of the permanent field crew from physical removal of infested leaves and pesticide application to monitoring, most of these jobs could be maintained.

Unfortunately, getting proprietary information from tomato packing operations to determine if the IPM program has been a commercial success has proven difficult. Although some growers have verbally stated that the IPM program has been successfully implemented, the data necessary to document the claims have not been forthcoming. However, the Campbell's–Sinalopasta Corporation in the state of Sinaloa, which has been using the IPM program in processing tomatoes for the past two growing seasons, did provide information which suggests the IPM approach has been effective. Data from the Sinalopasta company farm showed damage levels in fruit declining from 8.5% (2300 ha on standard conventional practices) in 1988–1989 to 2.2% (3000 ha on the IPM program) and 2.7% (1800 ha on the IPM program) in 1989–1990 and 1990–1991, respectively. This drop in percent damage occurred in spite of a 60% reduction in pesticide use from 2.45 kg a.i. ha^{-1} in 1988–1989 to 0.99 kg a.i. ha^{-1} in 1989–1990, and 0.84 kg a.i. ha^{-1} in1990–1991. Recognizing that population variation between years could account for the differences in percent damage and pesticide use, an untreated 10 ha plot was established in 1990–1991 to document *K. lycopersicella* populations. Fruit from this untreated plot showed 71.2% damage. Thus, the available data suggest that the IPM program will function economically in large scale commercial plantings.

The IPM program offers several additional benefits beyond the short-term economic gains. First, use of this program minimizes the potential for resistance development by reducing the amount of pesticide applied and by maximizing the impacts of the beneficial arthropods. Second, the program dramatically reduces the use of pesticides with high mammalian toxicity; methamidophos has an oral LD_{50} of approximately 13 mg kg^{-1} vs. abamectin, which has a contact toxicity in excess of 5000 mg kg^{-1}. Third, the reduced pesticide pressure provides less chance for fruit contamination. Fourth, the overall reduction in pesticide application serves to minimize the possibility of subvisual phytotoxic effects of pesticides on tomatoes (Welter et al., 1989).

ACKNOWLEDGMENTS

The authors appreciate the advice and support from the Confederacion de Asociaciones Agricolas del Estado de Sinaloa and Dr. Jose Rodriguez, the permission of F.J. Navarro and Dr. J.M. Ramirez Díaz for use of Campo Experimental land, and the gifts of control materials from Scentry, Inc., Sandoz Crop Protection, and Merck & Co. The Centro Reproductivo de Insectos Beneficos-GUASAVE kindly provided the *T. pretiosum*. The data and support of the Campbell Institute for Research and Technology (CIRT) and the Campbell's–Sinalopasta Co. are appreciated. The authors also appreciate the continuous support and encouragement of former CIRT vice President Dr. Allen M. Stevens, as well as the personal support and inspiration of Dr. Edwardo Alvarez Luna. Appreciation also is expressed to Drs. D. Schuster, M. Blua, T. Paine and M. Diawara for improvements to earlier drafts of the manuscript.

REFERENCES

Alvarado-Rodriguez, B., 1988. Manejo integrado de plagas en tomate industrial en Sinaloa. In: Taller Sobre el Manejo Integrado de Plagas en Tomate. CAADES, Culiacan, Sinaloa, Mexico, 1: 33–41.

Anonymous, 1979. Results of FDA surveillance of Mexican produce for pesticide residues (compliance program 7305.008). Bureau of Foods and Office of Assoc. Comm. for Reg. Affairs, FDA Admin., April 29, Washington, DC.

Baker, T.C., Staten, R.T. and Flint, H.M., 1990. Use of pink bollworm pheromone in the southwestern United States. In: R.L. Ridgway, R.M. Silverstein and M.N. Inscoe (Editors), Behavior-Modifying Chemicals for Insect Management. Marcel Dekker, New York, pp. 417–436.

Biever, K.D. and Hostetter, D.L., 1978. Use of entomopathogens in pest management systems for vegetables. In: G.E. Allen, C.M. Ignoffo and R.P. Jaques (Editors), Microbial Control of Insect Pests: Future Strategies in Management Systems. Natl. Sci. Foundation, USDA Workshop, Univ. Florida, Gainesville, pp. 186–194.

Brewer, M.J. and Trumble, J.T., 1991. Classifying resistance severity in field populations: Sampling inspection plans for an insecticide resistance monitoring program. J. Econ. Entomol., 84: 379–389.

Brewer, M.J., Trumble, J.T., Alvarado-Rodriguez, B. and Chaney, W., 1990. Beet armyworm, (Lepidoptera: Noctuidae) adult and larval susceptibility to fenvalerate, permethrin, and methomyl in managed habitats and selection experiments. J. Econ. Entomol., 83: 2136–2146.

Buckley, K.C., van Sickle, J.J., Bredahl, M.E., Belibasis, E. and Gutierrez, N., 1986. Florida and Mexico competition for the winter fresh market. USDA Agric. Econ. Rep. No. 556, USDA, Washington, DC.

Elizondo-Alapisco, D. and Alvarado-Rodriguez, B., 1988. Uso de avispitas *Trichogramma pretiosum* en tomate industrial en Sinaloa. In: Taller Sobre el Manejo Integrado de Plagas en Tomate. CAADES, Culiacan, Sinaloa, Mexico, 1: 100–106.

Fisher, R.A., 1949. The Design of Experiments. Oliver and Boyd, Edinburgh.

Griswold, M.J. and Trumble, J.T., 1985. Responses of *Spodoptera exigua* (Lepidoptera: Noctuidae) larvae to light. Environ. Entomol., 14: 650–653.

Jenkins, J.W., Doane, J.C., Schuster, D.J., McLaughlin, J.R. and Jiménez, M.J., 1990. Development and commercial application of sex pheromone for control of the tomato pinworm. In: R.L. Ridgway, R.M. Silverstein and M.N. Inscoe (Editors), Behavior-Modifying Chemicals for Insect Management. Marcel Dekker, New York, pp. 269–280.

Johnson, M.W., Oatman, E.R. and Wyman, J.A., 1980a. Effects of insecticides on populations of the vegetable leafminer and associated parasites on summer pole tomatoes. J. Econ. Entomol., 73: 61–66.

Johnson, M.W., Oatman, E.R. and Wyman, J.A., 1980b. Effects of pesticides on populations of the vegetable leafminer and associated parasites on fall pole tomatoes. J. Econ. Entomol., 73: 67–71.

Johnson, M.W., Oatman, E.R., Wyman, J.A. and van Steenwyk, R.A., 1980. A technique for monitoring *Liriomyza sativae* in fresh market tomatoes. J. Econ. Entomol., 73: 552–555.

Moar, W.J. and Trumble, J.T., 1990. Comparative toxicity of five *Bacillus thuringiensis* strains and formulations against *Spodoptera exigua* (Lepidoptera: Noctuidae). Fl. Entomol., 73: 195–197.

Oatman, E.R., 1988. Biological and integrated control of lepidopterous pests on tomato in California. In: Taller Sobre el Manejo Integrado de Plagas en Tomate. CAADES, Culiacan, Sinaloa, Mexico, 1: 96–97.

Oatman, E.R. and Kennedy, G.C., 1976. Methomyl-induced outbreak of *Lyriomyza sativae* on tomato. J. Econ. Entomol., 69: 667–668.

Oatman, E.R., Platner, G.R., Wyman, J.A., van Steenwyk, R.A.. Johnson, M.W. and Browning, H.W., 1983. Parasitization of lepidopterous pests on fresh market tomatoes in southern California. J. Econ. Entomol., 76: 452–455.

Pastemak, D.M., Twersky, M. and DeMalach, Y., 1979. Salt resistance in agricultural crops. In: H. Mussell and R.C. Staples (Editors), Stress Physiology in Crop Plants. Wiley, New York, pp. 127–142.

Ramirez Díaz, J.M., 1988. Investigacion sobre plagas de tomate en Sinaloa. In: Taller Sobre el Manejo Integrado de Plagas en Tomate. CAADES, Culiacan, Sinaloa, Mexico, 1: 178–182.

Rothschild, G.H.L., 1981. Mating disruption of lepidopterous pests: current status and future prospects. In: E.R. Mitchell (Editor), Management of Insect Pests with Semiochemicals. Plenum Press, NY, pp. 207–228.

Shelton, A.M. and Trumble, J.T., 1990. Monitoring insect populations. In: D. Pimintel (Editor), Handbook of Pest Management in Agriculture, 2nd Edn., Vol. 2. CRC Press, Boca Raton, FL, pp. 45–62.

Silverstein, R.M., 1990. Practical use of pheromones and other behavior-modifying compounds: overview. In: R.L. Ridgway, R.M. Silverstein and M.N. Inscoe (Editors), Behavior-Modifying Chemicals for Insect Management. Marcel Dekker, New York, pp. 1–8.

Toscano, N.C., Youngman, R.R., Oatman, E.R., Phillips, P.A., Jimenez, M. and Munoz, F., 1987. Implementation of an integrated pest management program for fresh market tomatoes. Appl. Agric. Res., 1: 315–324.

Trumble, J.T., 1985. Integrated pest management of *Liriomyza trifolii*: Influence of avermectin, cyromazine, and methomyl on leafminer ecology in celery. Agric. Ecosystems Environ., 12: 181–188.

Trumble, J.T., 1990. Vegetable insect control with minimal use of insecticides. J. HortScience, 25: 159–164.

Van Steenwyk, R.A. and Oatman, E.R., 1983. Mating disruption of tomato pinworm (Lepidoptera: Geliciidae) as measured by pheromone trap, foliage, and fruit infestation. J. Econ. Entomol., 76: 80–84.

Welter, S.C., Johnson, M.W., Toscano, N.C., Perring, T.M. and Varela, N., 1989. Herbivore effects on fresh and processing tomato productivity before harvest. J. Econ. Entomol., 82: 935–941.

Wiesenborn, W.D., Trumble, J.T. and Oatman, E.R., 1990. Economic comparison of insecticide-treatment programs for managing tomato pinworm (Lepidoptera: Gelichiidae) on fall tomatoes. J. Econ. Entomol., 83: 212–216.

Wyman, J.A., 1979. Effect of trap design and sex attractant release on tomato pinworm catches. J. Econ. Entomol., 72: 865–868.

Zehnder, G.W. and Trumble, J.T., 1985. Sequential sampling plants with fixed levels of precision for *Liriomyza* species (Diptera: Agromyzidae) in fresh market tomatoes. J. Econ. Entomol., 78: 138–142.