Economic Analysis of a *Bacillus thuringiensis*-Based Integrated Pest-Management Program in Fresh-Market Tomatoes

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ABSTRACT Economic analyses were conducted on fresh-market tomato plantings in 1992 and 1993 that compared the benefit of an integrated pest-management (IPM) program based on a registered *Bacillus thuringiensis* preparation with the current chemical-standard pesticide practices and an untreated control. The IPM program used three or four applications of *B. thuringiensis* as needed. The chemical-standard treatment consisted of seven to nine applications of methomyl and permethrin. The effect of each pesticide-use program on insect populations, fruit damage, yield, crop value, cost of control, and net profit was determined. The chemical-standard and IPM treatments reduced pest populations and damage, resulting in better yield and net profits as compared with the control treatment. In 1992, net profits were higher by ≈$500–1,000/ha in the IPM program as compared with the chemical-standard treatment. In 1993, the chemical-standard program performed slightly better by ≈$300/ha. However, given shipping prices over the past 5-yr period, the IPM approach would outperform the chemical-standard treatment in terms of net profit >80% of the time. In addition, the economic results from the IPM program are conservative because some significant benefits, such as a potential reduction in development of pesticide resistance, reduced soil compaction, less potential for damage to the environment, and less possibility of human health concerns, were not included.

KEY WORDS *Bacillus thuringiensis,* integrated pest management, economics

IN TERMS OF pesticide use, the $350 million/yr California fresh-market tomato industry is faced with several significant problems. Expansion of California's urban population has led to an increase in the political influence of environmental activists, labor unions, and consumer groups that are adopting increasingly antipesticide agendas and sponsoring ballot initiatives designed to restrict pesticide use (Trumble 1990). In addition, concerns about the pollution of ground water and fears of increased cancer risks have stimulated a surge in legislation dealing with pesticides (Trumble 1989). These bills and initiatives are evidence of the growing perception that consumers bear the burden of risk when pesticides are used, whereas growers reap the profits. Coupled with this is the continuing trend for reduction in registration of new pesticides as a result of the increased testing requirements and registration costs (Georghiou 1990). Thus, there exists a clear need to explore methods of minimizing pesticide use while maximizing, or at least not substantially lowering, net profits for producers of agricultural crops.

Accurate economic information on the benefits of specific pesticide-use plans is needed by both growers and consumers to ensure that the maximum benefit is being achieved with the minimum risk. This information can take the following two forms: (1) proof that the standard commercial programs are maximizing yield (and profits) while minimizing unnecessary use and (2) clear economic information on the benefit of use of alternative programs relying on pesticides with low mammalian toxicity that have broad legislative or public acceptance, or both.

Relatively few reports are available that document the economic benefits associated with specific pesticide-use programs on tomatoes. Wiesenborn et al. (1990) documented the optimum number of methomyl applications needed in proportion to density of the tomato pinworm, *Keiferia lycopersicella* (Walsingham), which would maximize economic return in relation to pesticide-input costs. Approximately eight applications provided optimal return in dollars for the investment in pest control. Walgenbach & Estes (1992) determined the losses in net profits in staked-tomato production caused by the tomato fruitworm, *Helicoverpa zea* (Boddie), and by the potato aphid, *Macrosiphum euphorbiae* (Thomas), associated with use of either carbaryl, *Bacillus thuringiensis* var. *kurstaki,* endosulfan, esfenvalerate, methomyl, or no treatment. With applications on a fixed 5- or 10-d schedule, broad-spectrum pesticides were found to be most prof-

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itable. In Sinaloa, Mexico, an integrated pest-management (IPM) program for a complex of pests based on combined use of the pheromone mating-disruption technique, *B. thuringiensis*, abamectin, and parasite releases was economically equivalent to commercial-grower practices in the autumn planting but proved far superior in the winter and spring crops (Trumble & Alvarado-Rodriguez 1993).

For the study reported here, our objective was to generate data that allowed an economic analysis comparing the benefit of the use of conventional pesticide practices currently in use in California with a program based on a registered *B. thuringiensis* preparation. The experiments were designed to permit an assessment of the effect of insect damage and pesticide-use patterns on crop yield and a determination of total fresh-market crop value, costs of control programs, and net profits resulting from each approach.

Table 1. Fixed and variable costs for production of fresh-market tomatoes

Fixed costs[a]	$/ha	Variable costs	$/carton
Water	494.20	Harvest	1.10
Seed	24.10	Sales	2.30
Transplants	401.29		
Scouting	35.00		
Labor	161.62		
Miscellaneous[b]	260.79		
Methomyl	44.47		
Permethrin	56.83		
B. thuringiensis	24.71		
Pesticide application[c]	62.73		

[a] Water costs based on 150.6 cm/ha (24 in/acre); seed and transplant costs based on 14,332 plants per hectare; labor includes some transplanting and watering costs.

[b] Includes overhead, fertilizer, and several minor additional expenses.

[c] Cost of pesticide application includes only the tractor and driver; pesticides listed separately. See text for chemicals used in each treatment and for numbers of applications.

Materials and Methods

Experimental plantings of fresh-market tomatoes ('Petoseed 7718VFN') were established at the University of California's South Coast Research and Extension Center in Orange County, California, during the summer seasons of 1992 and 1993. Tomatoes were transplanted on 30 June in 1992 and 15 June in 1993. Plants were grown using local commercial practices and harvested on 8 October in 1992 and 16 September in 1993.

The following three treatments were evaluated in a randomized complete-block design: (1) a chemical-standard approach using seven to nine weekly treatments (1.1 kg [AI]/ha of methomyl 1.9 liquid [DuPont, Wilmington, DE] plus 0.22 kg [AI]/ha permethrin 3.2 emulsifiable concentrate [FMC, Philadelphia, PA]), (2) an IPM program consisting of three or four, as needed, applications of *B. thuringiensis* (Javelin, Sandoz, Des Plaines, IL) at 2.47 kg (AI)/ha, and (3) an untreated control. All applications included spreader sticker at 0.04% (Activator 90, Loveland Industries, Greeley, CO). Applications of all pesticides were made with a tractor-mounted boom sprayer with six nozzles per row. Disc-type nozzles incorporated D3 orifice disks, #25 cores, and 50 mesh screens. Operating pressure was 7.3 kg/cm^2, delivering 935 liters/ha.

Dates of application for the chemical-standard treatments were 6, 13, 20, and 27 August; 3, 10, 17, and 24 September; and 1 October in 1992. For 1993, the chemical-standard plots were treated weekly on 27 July; 3, 10, 19, and 26 August; and 2 and 9 September. This pattern of application reportedly provides an optimal return for the pesticide dollars invested (Wiesenborn et al. 1990) and closely approximates the number of applications used by most fresh-market tomato growers in California (Landels 1988).

The IPM plots received applications on 6, 20, and 27 August and 17 September in 1992 and 27 July and 3 and 26 August in 1993. In an effort to increase efficacy by reducing potentially undesirable effects of UV radiation on pesticide residue (Griego & Spence 1978, Pozsgay et al. 1987), spray applications for all materials were made in the evening. Timing of applications was based on weekly scouting for presence of pest larvae. Five-minute counts were made in each plot for *S. exigua* and *H. zea*. Leafminer and parasite populations were evaluated weekly by counting leafminer pupae and dead adult parasites in four (22.9 by 28 cm) trays per replicate from mid-August until harvest (after Johnson et al. 1980b, Zehnder & Trumble 1985a).

Each treatment was replicated four times; each replicate consisted of eight rows of tomatoes on 1.5-m centers by 20 m in length. All mature green-to-red fruit large enough to be potentially marketed from the center two rows of each plot were harvested, counted, and weighed. Two hundred fruit per replicate (800 per treatment) were selected randomly and inspected for damage done by key pests.

The costs associated with pesticide applications were calculated by determining commercial-pesticide costs on a per-hectare basis (averaged from three pesticide suppliers) and adding the labor and equipment costs for the application by ground equipment (Anonymous 1981, 1988). The horticultural, harvest, and marketing costs associated with commercial production were provided by three growers; values were averaged to produce a standardized cost (Table 1). All costs for each grower were similar, with the exception of water costs. The cost of water ranged from $250/ha for well-drawn water to nearly $500 for water purchased from a local water district. The higher cost was selected because two of the three growers purchased water, and use of the high cost would make the net profit results more conservative. Irrigation costs are generally predictable in California, because the period between May and November is the dry season and because rain is infrequent and light. No rain fell during the course of our study in either year.

Insect population levels, fruit characteristics, productivity, and tomato damage from insects were analyzed with analysis of variance (ANOVA) followed by Tukey's honestly significant difference test (SuperANOVA, Abacus Concepts, Berkeley, CA). Significance was determined at the $P < 0.05$ level.

All values were standardized on a per-hectare basis by scaling up yields from the research plots. The economic analyses were conducted by determining the potential gross profit from the crop (value of the marketable portion of the crop minus the horticultural costs needed to produce and harvest the crop). The costs associated with insect control were not included in the horticultural expenses and, thus, not included in the gross profits, and, therefore, comparisons could be made between control strategies. Net profits then were calculated as the gross profit from each treatment minus the costs of pesticides and their application. Both net profits and gross profits were calculated over a range of carton values. Free-on-board values for harvest dates in September and October were obtained from the Federal–State Market News Service, Sacramento, CA. Free-on-board prices during September and October for the past few years from San Joaquin County, the largest tomato producing region in California, were used in the analyses. Because most growers currently employ scouts (generally for disease monitoring, but monitoring for insects in the chemical standard is also common to catch migrations and outbreaks) and because the cost of scouting is minimal compared with the aggregate of other costs (Table 1), the expenses associated with scouting were assumed to be similar among the programs.

Results and Discussion

Leafminer populations were significantly higher in the chemical-standard treatment as compared with the IPM or control treatments (five of eight dates in 1992, six of six dates in 1993) (Fig. 1). The increase in leafminers is consistent with previous reports of the use of methomyl or permethrin, or both, causing leafminer resurgence (Oatman & Kennedy 1976, Johnson et al. 1980b, Lange et al. 1980). One possible explanation of this resurgence is the negative effect of the pesticides on populations of leafminer parasites (Fig. 2). Numbers of dead parasites per replicate were consistently higher in the chemical-standard treatment as opposed to either of the other treatments. The significance of leafminer suppression provided by such parasite populations has been demonstrated on a variety of vegetable crops for both *L. trifolii* and *L. sativae* Blanchard (Hills & Taylor 1951, Wene 1955, Getzin 1960, Oatman & Kennedy 1976, Johnson et al. 1980a, Trumble 1985). However, these results are circumstantial and other explanations, such as hormoligosis, are possible (Zehnder & Trumble 1985b).

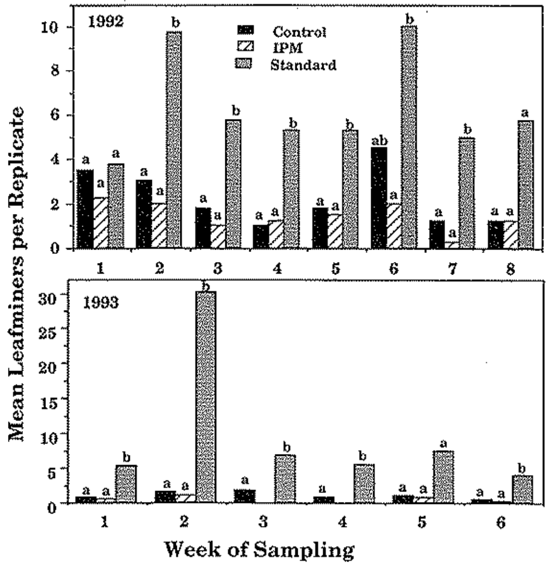

Fig. 1. Mean number of leafminers per replicate in the untreated control and the IPM and chemical-standard treatments in tomatoes during 1992 and 1993. Samples were collected weekly from 12 August 1992 and from 2 August 1993. Letters above bars (within sampling dates) indicate differences at the $P < 0.05$ level (Tukey's HSD test).

The IPM and chemical-standard programs did not differ significantly in fruit damage in either year, but both had substantially lower insect damage than the control treatment (Table 2). Whereas total damage from insects was similar between years in the control treatments (≈20%), the IPM and chemical-standard treatments had substantially lower insect damage in 1992 compared with 1993 (IPM = 3 versus 14.75%; chemical standard = 2 versus 9%, respectively). The increased damage observed in 1993 was caused primarily by populations of *K. lycopersicella* and *Lygus lineolaris* (Palisot de Beauvois), which individually were not suppressed significantly by the chemical-standard or IPM programs (Table 2).

Within years, total productivity (cartons per hectare), average fruit size, and number of fruit per replicate were not significantly different (Table 3). However, both total productivity and productivity adjusted for insect damage (i.e., marketable-fruit production) followed a general

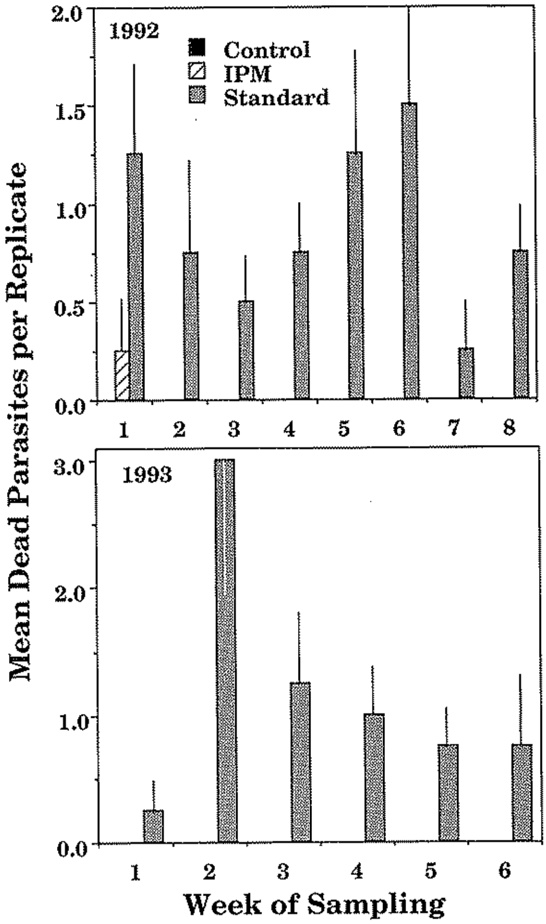

Fig. 2. Mean number of dead adult parasites of leafminers per replicate in the untreated control and the IPM and chemical-standard treatments during 1992 and 1993. Samples were collected weekly from 12 August 1992 and from 2 August 1993. Lines above bars delineate standard errors. ANOVA and post hoc analyses were inappropriate because of the lack of variation in some treatments (zeros) violates the assumptions of ANOVA.

trend, with chemical-standard treatment > IPM treatment > control treatment. In 1992, the marketable-fruit production was significantly greater in the IPM and chemical-standard treatments as compared with the control treatment. Thus, the pesticides and rates of application were not having a significant negative effect on plant productivity such as that noted by Welter et al. (1989), and the densities of leafminers in our study were not high enough to cause any noticeable yield effects.

Despite the higher insect damage in the IPM treatment (3%) as compared with the chemical standard (2%) in 1992, the net profits from the IPM approach were equal to or better than the chemical-standard approach (up to ≈$9 per carton; Fig. 3). For carton values from $3 to $8, net profits in the IPM treatment showed an ≈$700–1,000/ha improvement over the chemical-standard program. When values went above $9 per carton, the higher yields in the chemical-standard treatment resulted in increasingly greater net profits. At $12 per carton, the additional net profit from the chemical standard was ≈$1,400/ha.

In 1993, fewer pesticide applications in the chemical-standard treatment, coupled with a relative increase in damage in the IPM program, resulted in substantially reduced differentials in net profits in the IPM program as compared with the chemical-standard approach. For carton values <$6, the IPM program still provided a better net profit of ≈$500/ha. However, when values went above $6 per carton, the best net profits were achieved with the chemical-standard treatment.

Free-on-board value at harvest is a critical factor in determining profits or losses in tomato production. In 1992, harvest in the 2nd wk of October produced a net benefit of ≈$700/ha by using the IPM program as compared with the chemical-

Table 2. Fruit damage by key pest insects from insect-suppression programs in fresh-market tomatoes

Treatment and statistics	Mean no. of fruit damaged				
	H. zea	*S. exigua*	*K. lycopersicella*	Lygus + tomato bug	Total damage[a]
			1992		
Control	4.50a	17.25a	3.00a	14.50a	39.50a
IPM	1.50b	1.25b	0.50b	2.75b	6.00b
Standard	0.25b	0.75b	0.00b	3.00b	4.00b
P value	0.046	0.001	0.002	0.001	0.001
F (df 2, 9)	4.43	258.85	13.28	51.09	164.59
			1993		
Control	2.25a	12.25a	12.75a	11.50a	38.75a
IPM	0.25b	7.75a	12.25a	9.25a	29.50ab
Standard	0.00b	6.00a	5.75a	6.25a	18.00b
P value	0.005	0.076	0.254	0.281	0.029
F (df 2, 9)	9.95	3.48	1.60	1.47	5.38

Mean number of fruit damaged from samples of 200 per replicate. Numbers in columns followed by the same letter are not significantly different at the $P < 0.05$ level, Tukey's HSD test.

[a] Total damage includes losses to *Manduca* spp. and other relatively rare pests.

Table 3. Productivity analyses (in means) from insect-suppression treatments in fresh-market tomatoes in 1992 and 1993

Treatment and statistics	Cartons/ha	Marketable cartons/ha[a]	Weight/fruit, g	No. fruit/plot
		1992 Productivity		
Control	2,259.02a	1,810.33a	2.79a	1,697.25a
IPM	2,561.96a	2,485.42b	2.79a	1,891.75ab
Standard	2,702.93a	2,649.68b	2.86a	2,095.50b
P value	0.110	0.001	0.697	0.040
F (df 2, 9)	2.84	14.99	0.38	4.67
		1993 Productivity		
Control	3,302.72a	2,657.18a	2.56a	2,286.50a
IPM	3,327.60a	2,843.85a	2.48a	2,243.50a
Standard	3,516.10a	3,200.40a	2.48a	2,367.00a
P value	0.544	0.069	0.637	0.643
F (df 2, 9)	0.65	3.64	0.48	0.46

Means within years in columns followed by the same letter are not significantly different at the $P < 0.05$ level, Tukey's HSD test.

[a] Marketable cartons per hectare refers to cartons per hectare minus yield losses to insects.

standard treatment (Table 4; Fig 3). In 1993, harvest in the 3rd wk of September resulted in a net benefit of ≈$500 for the chemical-standard treatment as opposed to the IPM approach. However, because free-on-board values fluctuate, producers need to be concerned with price trends or averages. In September and October for the past 5 yr, free-on-board prices averaged ≈$5.75 per carton for large fruit, with a value of >$6 per carton reached on only eight out of 30 possible dates (Table 4). Therefore, mean net profit to the growers would be at least equivalent to and, on average, better with the IPM program than with the chemical-standard approach.

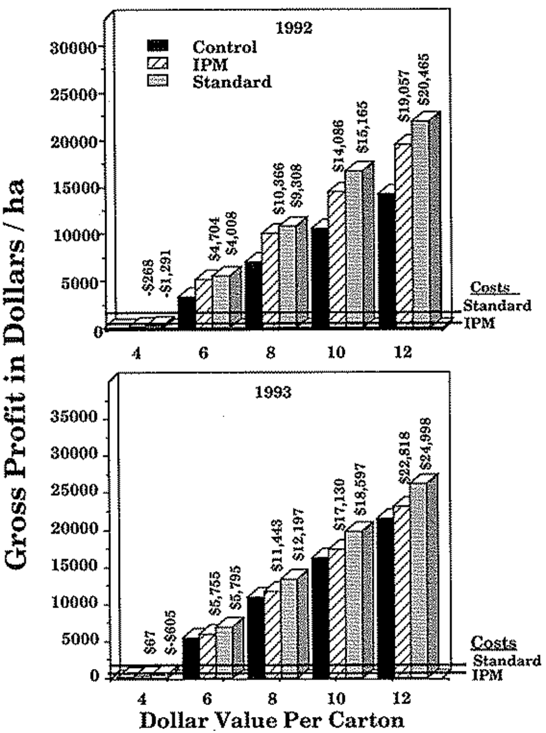

Fig. 3. Net-profit analysis from fresh-market tomato plantings in 1992 and 1993. The height of the bars indicates the potential gross profit of the crop when the market value (dollar value of the cartons) changes. Horizontal lines show the cost of the chemical and the IPM strategies. The net profits (gross profit from the crop minus the cost of pest control) are shown directly above the chemical standard and IPM program bars.

The benefits of the IPM program extend beyond the maintenance of short-term economic return. With reduced frequency of chemical application and the negligible disruption of natural enemies, the potential reduction in the development of insecticide resistance has considerable long-term economic implications. Pesticide resistance to methomyl or permethrin has been reported for *S. exigua*, *K. lycopersicell*, and *L. trifolii* (Sanderson et al. 1989; Brewer et al. 1990, 1993).

The IPM strategy offers significant advantages for a variety of additional factors that were not included in the economic analysis. These include the following four factors: (1) reduction in soil compaction because fewer trips are made through the field, (2) a substantially reduced potential for environmental contamination from pesticides or air pollutants generated by farm equipment, (3) potential advantages in marketing fruit as IPM or organic produce, and (4) use of compounds that are less toxic to mammals. The acute oral LD_{50} for methomyl equals 17 mg/kg. *B. thuringiensis* has proven so nontoxic that no LD_{50} values have been established for mammals. Therefore, the potential for human health concerns also is reduced in the IPM program. Thus, the long-term economic and environmental advantages of using the IPM program probably are understated in these analyses.

Two caveats apply. These results should not be extrapolated to fresh-market tomato systems

Table 4. Free-on-board values per carton for large, mature green tomatoes in California

Year[a]	Week of September				Week of October	
	1	2	3	4	1	2
1989	5.0–6.0	4.0	3.0–7.0	6.0	7.0	7.0
1990	4.5–5.5	5.0	4.0–5.0	5.0	5.0–6.0	7.0–9.0
1991	4.0–5.0	5.0–5.5	3.0–4.0	3.0–4.0	3.0–5.0	4.0–50
1992	5.0	6.0	6.0	6.0	6.0	6.0–7.0
1993	8.0–10.0	8.0	7.0	5.0	5.0	5.0

[a] Federal–State Market News Service, large U.S. #1 grade, San Joaquin Valley.

in which aircraft application primarily is used. In some areas, variability in the pest complex could also effect the net benefit of the IPM program.

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