Economic Comparison of Insecticide Treatment Programs for Managing Tomato Pinworm (Lepidoptera: Gelechiidae) on Fall Tomatoes

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ABSTRACT The efficacy and economics of various insecticide treatment programs for preventing fruit damage caused by tomato pinworm, *Keiferia lycopersicella* (Walsingham), on fall plantings of staked tomatoes, *Lycopersicon esculentum* Mill., were compared during 1982–1984. Methomyl (1.0 kg [AI]/ha) was used in all treatment programs. Weekly or biweekly applications of insecticide begun when larval density in foliage was ≥10 larvae per 3 m of row resulted in less fruit damage than in untreated plots, but the damage increased throughout most of the growing season. Of the treatment programs examined, maximum net revenue (crop value minus treatment program costs) was observed when weekly applications were started at 3–4 larvae per 3 m of row (approximately 0.5 larvae per plant). Insecticide applications begun at this threshold produced less fruit damage than in untreated plots, and damage was stable throughout the growing season. Sampling larvae on foliage provided a direct method for accurately timing the start of weekly insecticide applications.

KEY WORDS Insecta, *Keiferia lycopersicella*, tomatoes, chemical control

THE PHYSICAL LAW of diminishing returns applied to pest management predicts that as a management input increases above a certain level, the rate of increase in crop yield will be reduced (Mumford & Norton 1984). Optimal use of insecticide, from the perspective of economics, occurs when the rate of increase in crop value equals the rate of increase in insecticide costs (Headley 1982). At this point the net revenue, or economic benefit of applying insecticide, is maximized.

The tomato pinworm, *Keiferia lycopersicella* (Walsingham), is a key pest of tomatoes, *Lycopersicon esculentum* Mill., in the southern portions of California, Texas, and Florida (Harding 1971, Wolfenbarger et al. 1975, University of Calif. 1982). As well as reducing net revenue, unnecessary applications of a broad-spectrum insecticide to manage tomato pinworm would promote the development of insecticide resistance and decrease populations of natural enemies of tomato pinworm (Oatman 1970, Oatman et al. 1979) and those of secondary pests such as *Liriomyza sativae* Blanchard (Johnson et al. 1980).

Proper timing of insecticide application is difficult because the tomato pinworm's long ovipositional period, short generation time, and adult movement between fields combine to make populations increase rapidly without discrete generations (Elmore & Howland 1943). Van Steenwyk et al. (1983) improved the timing of applications on fall plantings of tomato by using pheromone traps. Starting weekly applications of insecticide when pheromone trap-catch attained a certain level, rather than on a calendar basis, permitted growers to reduce the number of applications without significantly increasing yield loss. However, this method was effective only when preceding plantings did not contribute immigrant moths. Managing tomato pinworm by beginning applications based on a threshold other than pheromone trap catch would be advantageous in areas where summer plantings also are grown. Peña et al. (1986) estimated an economic injury level for infestations of tomato pinworm on spring tomatoes based on the density of larvae in foliage. Our objective was to compare the efficacy and economics of various insecticide treatment programs for managing tomato pinworm on fall tomatoes.

Materials and Methods

Studies were done during 1982–1984 on fall plantings of staked tomatoes at the University of California South Coast Field Station in Santa Ana, Orange County, Calif. Tomato seedlings (Petoseed 7718) were transplanted during mid-July of each year. Transplants were placed every 0.46 m into 16 rows that were 61 m long and 2.3 m apart. Plantings were sprinkler irrigated for the first two weeks and drip irrigated thereafter. Conventional cultivation practices were followed, and insecticide other than the treatment programs was not applied.

We examined treatment programs that began insecticide applications at different thresholds (Table 1). Treatment programs were arranged in a randomized complete block design with each block consisting of four adjacent rows. Each experimental unit (plot) was a 12.2-m-long section of a block.

Table 1. Insecticide treatment programs, total number of insecticide applications, and fruit damage by tomato pinworm

Treatment program	Treatment threshold[a]	No. weeks sampled	1st application date	No. applications	% Total fruit damage[b]
1982					
Untreated	—	0.0	—	0	29.8 ± 1.5 (40)a
Biweekly	10	1.0	Aug. 27	7	9.9 ± 0.9 (40)b
Weekly	10	1.0	Aug. 27	14	5.5 ± 0.7 (40)b
Weekly	32	2.0	Sept. 10	12	8.9 ± 0.9 (40)b
1983					
Untreated	—	0.0	—	0	6.5 ± 0.8 (56)a
Weekly	19	9.5	Oct. 18	4	2.9 ± 0.3 (56)b
Weekly	7	7.0	Sept. 30	7	1.3 ± 0.3 (56)c
Weekly	4	5.0	Sept. 16	9	0.3 ± 0.1 (56)d
Weekly	0.5	2.0	Aug. 26	12	0.07 ± 0.04 (56)d
1984					
Untreated	—	0.0	—	0	18.9 ± 0.9 (68)a
Weekly	3	2.5	Aug. 29	7	2.1 ± 0.2 (68)b
Weekly after bloom	—	0.0	Aug. 15	9	1.7 ± 0.2 (68)b
Each time density exceeded	7	14.0	Aug. 31	9	2.3 ± 0.3 (68)b
Each time density exceeded	3	14.0	Aug. 31	11	1.8 ± 0.2 (68)b

[a] Larvae per 3 m of row.
[b] $\bar{Y} \pm$ SE (n); Means within a year followed by the same letter are not significantly different (LSD test of data transformed $[Y + 0.5]^{1/2}$, $P > 0.05$).

Four replicates were included in each year. Methomyl (1.0 kg [AI]/ha) with 0.4% surfactant (Leaf Act 40, Pure-Gro, West Sacramento, Calif.) was used in all applications. Sprays of 935 liter/ha at 7 kg/cm^2 were made with a tractor-mounted boom sprayer employing six nozzles that contained D-3 orifice disks, #25 cores, and 50-mesh screens. The mean density of larvae in the untreated plots was used to decide when to begin insecticide applications during 1982 and 1983. An exception during 1983 occurred when the mean larval density within plots of the treatment program was used to initiate insecticide applications at 0.5 larvae per 3 m. The mean density of larvae in each treatment program (except for the treatment program with applications begun at bloom) was used to decide when to begin insecticide applications during 1984.

Density of tomato pinworm in foliage was estimated by counting leafmining and tentiform larvae in 3 m of a row. Sampling was restricted to the two inner rows of a plot, and the same 3 m of a row was not sampled more than once in a 7-wk period. Foliage was sampled twice weekly beginning 19 August 1982, 19 August 1983, and 13 August 1984. Fruit damage was assessed by harvesting all mature green to ripe fruit in the entire plot and examining beneath the calyx for tomato pinworm feeding damage. Plots were harvested twice weekly from 13 October to 15 November 1982, 3 October to 17 November 1983, and 27 September to 21 November 1984.

Percentages of damaged fruit in each year (transformed $[Y + 0.5]^{1/2}$) were analyzed as a split-block design (Steel & Torrie 1980), because samples were taken from the same plots over time. Treatment program means across sampling dates were compared with least significant difference (LSD) tests (Steel & Torrie 1980). All statistical tests were considered significant if $P \leq 0.05$.

Treatment programs in each year were compared economically by examining the influence of the number of spray applications on net revenue. The proportion of undamaged fruit was averaged across dates, and gross revenue was determined by multiplying this proportion by the average value per hectare of fresh market tomatoes grown in Orange County during 1986 ($15,561; California Agricultural Statistics Service 1987). Net revenue was determined by subtracting management cost (i.e., the cost of sampling and applying insecticide) from gross revenue. Sampling cost was the weekly cost of sampling a hectare of staked tomatoes ($6.18; quoted by a pest control advisor) multiplied by the number of weeks that sampling was required. Insecticide application cost was the cost per hectare of a methomyl application ($48.17 for 1 kg [AI]/ha; quoted by a commercial applicator) multiplied by the number of applications. Net revenue was regressed by piecewise linear regression (Neter et al. 1985) against the total number of insecticide applications in each treatment program. Regressions were weighted by $1/s^2$ to compensate for unequal variances. Regression coefficients were considered significant if $P \leq 0.05$.

Results and Discussion

The percentage of fruit damage across sampling dates during 1982 was significantly different only between the untreated plots and the plots treated with insecticide (Table 1). Fruit damage also varied between dates ($F = 21.8$; df = 9, 27; $P = 0.0001$); damage in all treatment programs increased until approximately 8 November and decreased slightly

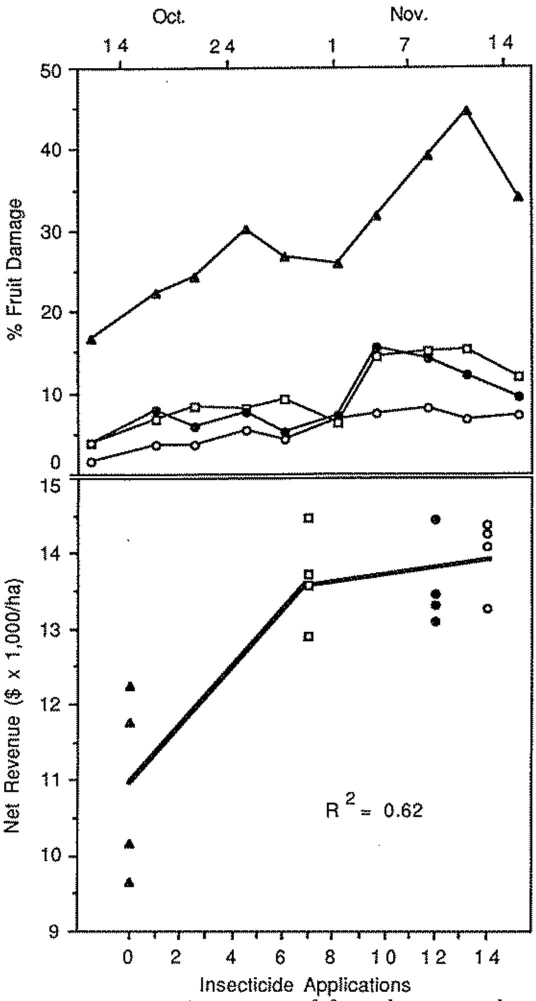

Fig. 1. 1982: Percentage of fruit damage and net revenue vs number of insecticide applications. Insecticide treatment programs were untreated (triangles), applications biweekly after 10 larvae per 3 m (squares), applications weekly after 32 larvae per 3 m (closed circles), and applications weekly after 10 larvae per 3 m (open circles).

thereafter (Fig. 1). Similar peaks in tomato pinworm density during the fall was observed by Oatman et al. (1979). The upward trend in fruit damage suggests that insecticide applications were begun when larval densities were too high, because applications as often as weekly did not stabilize damage levels.

Net revenue during 1982 increased as the number of insecticide applications increased (Fig. 1). Although the rate of increase in net revenue declined above seven applications, a maximum in net revenue was not achieved. Absence of a maximum indicates that none of the treatment programs during 1982 can be identified as economically optimum for tomato pinworm management. Therefore, insecticide applications during 1983 were begun when larval densities were lower.

The percentage of fruit damage across sampling dates during 1983 was significantly different among all treatment programs except weekly applications begun at 0.5 and 4 larvae per 3 m (Table 1). A treatment program by date interaction occurred ($F = 4.7$; df = 52, 156; $P = 0.001$) that was seen as an upward trend in fruit damage varying in magnitude between treatment programs. The upward trend was strongest in untreated plots; it was reduced in plots where insecticide was applied weekly after the density had reached 19 larvae per 3 m and absent in plots of the other treatment programs (Fig. 2). Earlier initiation of weekly insecticide applications, when larval densities were low, prevented subsequent increases in fruit damage. This result is expected if fruit damage is related to pest density, because exponential population growth by tomato pinworm (as shown in Fig. 1 of Oatman et al. 1979) would cause pest density to increase more rapidly between weekly applications of insecticide as population levels increased.

Net revenue during 1983 increased as the number of insecticide applications increased to nine applications (Fig. 2). Above nine applications, the management costs exceeded the gain in gross revenue. Diminished net revenue with increased number of insecticide applications would be expected; whereas fruit damage would decrease and asymptote near zero as the number of applications increased, the total cost of applying insecticide would increase linearly. Of the treatment programs examined, maximum net revenue occurred when weekly applications of insecticide were begun at a density of four larvae per 3 m.

The percentage of fruit damage across sampling dates during 1984 was significantly different only between the untreated plots and the plots treated with insecticide (Table 1). A treatment program by date interaction occurred ($F = 3.39$; df = 64, 192; $P = 0.001$) that was due to different seasonal trends in fruit damage between untreated plots and plots treated with insecticide. Although damage in the untreated plots increased until 1 November and then sharply declined, damage in the treated plots remained stable throughout the growing season (Fig. 3). Insecticide applications in 1984 most likely were begun early enough to prevent population increases by tomato pinworm.

Net revenue during 1984 decreased as the number of insecticide applications increased above seven applications (Fig. 3). Similar to 1983, weekly applications of insecticide that began at a density of three larvae per 3 m produced the greatest net revenue. Applying insecticide each time larval density reached a certain level (see Table 1) resulted in diminished net revenue, suggesting that applications more often than weekly are not economically advantageous for managing tomato pinworm on fall plantings in coastal southern California.

We have not determined if insecticide can be applied less frequently than weekly and still pro-

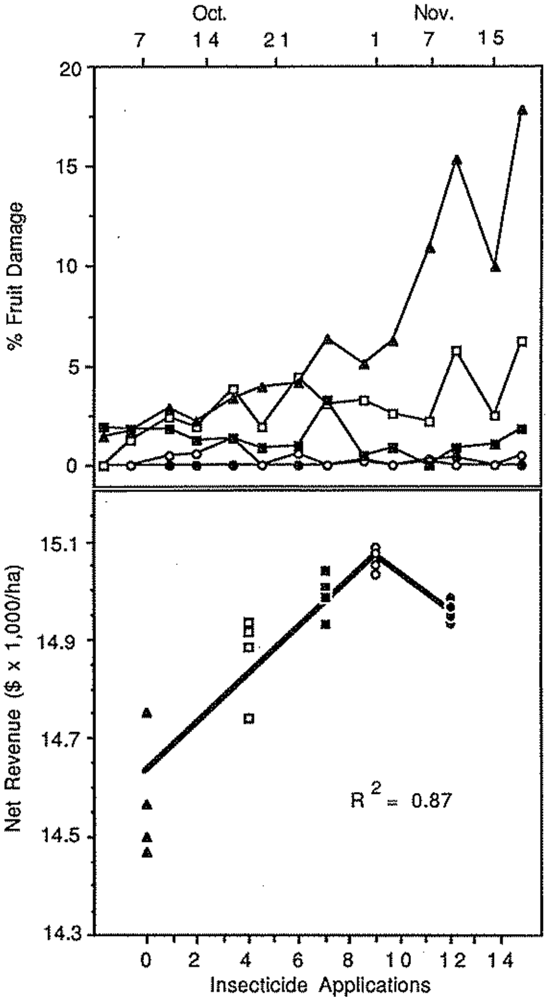

Fig. 2. 1983: Percentage of fruit damage and net revenue vs number of insecticide applications. Insecticide treatment programs were untreated (triangles), applications weekly after 19 larvae per 3 m (open squares), applications weekly after 7 larvae per 3 m (closed squares), applications weekly after 4 larvae per 3 m (open circles), and applications weekly after 0.5 larvae per 3 m (closed circles).

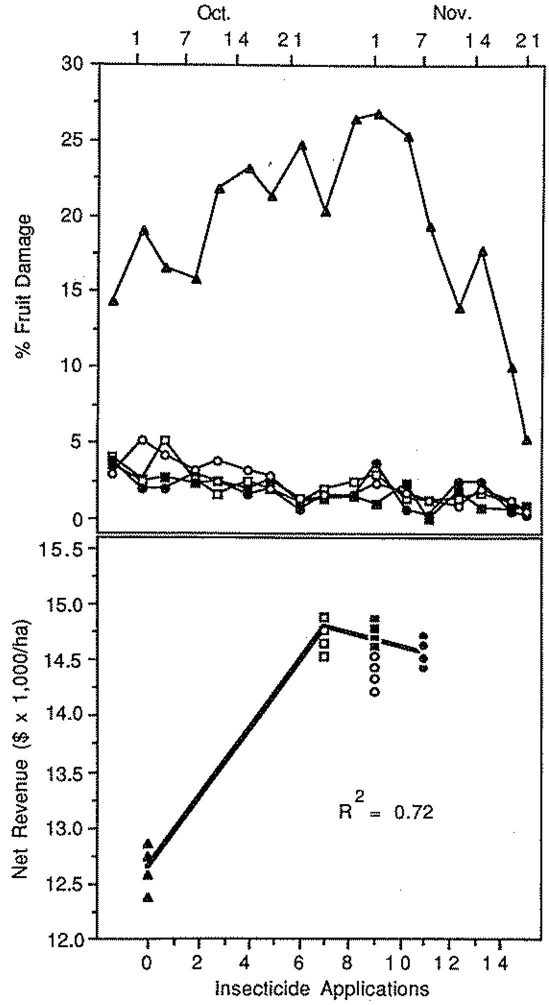

Fig. 3. 1984: Percentage of fruit damage and net revenue vs number of insecticide applications. Insecticide treatment programs were untreated (triangles), applications weekly after 3 larvae per 3 m (open squares), applications weekly after bloom (closed squares), applications each time density exceeded 7 larvae per 3 m (open circles), and applications each time density exceeded 3 larvae per 3 m (closed circles).

duce economically acceptable results. Although biweekly applications in 1982 produced less net revenue than weekly applications begun at the same larval-density threshold (10 larvae per 3 m), this likely was because the threshold was too high. Applications less often than weekly may produce acceptable net revenue if begun earlier when larval populations are low and increasing slowly. Decreasing larval development rate and survival due to decreasing temperature and host suitability (Lin & Trumble 1985) also may permit longer intervals between insecticide applications later in the fall.

Results indicate that weekly insecticide applications should be started at 0.46–0.62 larvae per plant based on the plant density of 6.5 plants per 3 m used in our trials. This larval density threshold agrees with the economic injury level of 0.45 larvae per plant[1] estimated by Peña et al. (1986). The utility of this economic injury level is supported by the differences in growing practices between their study and ours. Whereas we used staked tomato plants grown in coastal southern California during the fall, they used bedded tomato plants grown in Florida during the spring. Applying insecticide each time this threshold was reached, consistent with the economic threshold concept (Stern

[1] The original value of 0.67 larvae per plant has been corrected by being squared (J. E. Peña, University of Florida, Tropical Research and Education Center, personal communication).

et al. 1959), did not increase net revenue compared with weekly applications. Deciding if density has reached this low economic injury level may be easier with improved sampling, for example, concentrating on the lower portion of the plant (Peña et al. 1986, Wellik et al. 1979) or sampling sequentially (Wolfenbarger et al. 1975).

Beginning weekly applications of insecticide at three or four larvae per 3 m corresponded to nine applications in 1983 and seven applications in 1984. Similarly, Van Steenwyk et al. (1983) found that the number of weekly methomyl applications for tomato pinworm management could be reduced from 11 to 8 without a significant increase in the percentage of fruit damage when applications were started based on pheromone trap catch. When applied weekly, approximately eight properly timed applications of insecticide appear to provide optimal management of tomato pinworm on fall tomatoes in coastal southern California. Sampling larvae on foliage would permit growers to accurately time the start of these applications in regions where immigration from summer plantings of tomato diminishes the effectiveness of using pheromone traps to estimate infestation levels and time insecticide applications accurately.

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