Economics and Environmental Impact of a Sustainable Integrated Pest Management Program in Celery

JOHN T. TRUMBLE, WILLIAM G. CARSON, AND GREGORY S. KUND

Department of Entomology, University of California, Riverside, CA 92521

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ABSTRACT Studies were conducted on celery plantings in 1992 and 1993 (experimental plantings) and 1995 (commercial field) that compared the benefit of current chemical standard pesticide practices with an integrated pest management (IPM) program based on *B. thuringiensis*. In experimental plantings at a field station, the chemical standard treatment consisted of 9 applications of methomyl and permethrin. The IPM program used 3 or 4 applications of *B. thuringiensis*, the need for which was determined by sampling insect populations for established thresholds. Each control program was evaluated for yield, crop value, and cost of the control strategies. A partial budget was constructed that determined net profits for all treatments. Both the chemical standard and IPM treatments reduced pest populations and damage, resulting in better yield and net profits as compared with the control treatment. The reduced input costs of the IPM program resulted in better economic returns in both years. In 1992, net profits were higher by $1,485/ha. In 1993, when celery prices were lower, net profits with the IPM program were higher by $614/ha. The program was validated in 1995 on a commercial celery operation in Ventura County, California. The IPM program generated a net profit more than $410/ha higher than that of the grower's chemical program. Because reduced potential for insecticide resistance in the IPM program was not accounted for in the economic analysis, and the validation trials were conducted on a progressive operation using ≈40% fewer pesticides than most celery producers, the results of the economic analyses are conservative.

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

COMPARATIVE STUDIES of the economic benefits of IPM programs versus conventional chemical pesticide programs are relatively rare. This is surprising, because economics are fundamental to the concept of IPM (Stern et al. 1959, Pedigo et al. 1986). There are many examples of development of IPM programs (Evans and Scarisbrick 1994, Teng 1994, Zehnder 1994, Chau 1995), how to incorporate some aspect of control into IPM programs (Showers et al. 1990, Metcalf 1994), comparisons between programs for effectiveness in controlling an insect pest (Smith et al. 1995), and even examples of impact on markets (White and Wetzstein 1995) or social policy (Bentley and Andrews 1991). Some studies report the impact of adoption of IPM programs on environmental concerns (Babu and Hallam 1989, Moffitt 1993, and references therein). In addition, there are many reports on how to foster implementation of IPM strategies (e.g., Vorley 1993, Hutchins 1995, Ramirez and Mumford 1995). All of these represent important additions to our knowledge of IPM. However, there are relatively few studies with field crops that document an increase in net profits with implementation of IPM programs as compared with conventional pesticide programs (Musser et al. 1986, McNamara et al. 1991).

The Walgenbach and Estes (1992) study of a staked tomato system documented the net profits associated with the use of various control strategies. In this case, using typical grower application schedules, the broad spectrum pesticides produced the best net profits. In an exceptionally detailed study of 72 combinations of various treatments, Takele et al. (1993) reported that specific combinations of miticides, nematicides, plant growth regulators, and fertilizer produced optimum economic returns for citrus producers. At least 2 other studies on tomatoes and 1 on strawberries also presented detailed net profit comparisons between chemical standard and IPM programs (Trumble and Alvarado-Rodriguez 1993, Trumble and Morse 1993, Trumble et al. 1994). In these studies, substantial net profit increases were realized by growers adopting IPM strategies. Essentially, the reduction in input costs associated with reduced pesticide use more than offset any potential losses in income from occasionally smaller yields.

For the study reported here, our objectives were to generate an economic analysis comparing the benefit of the use of standard pesticide practices currently in use in California with a program based on scouting using treatment thresholds, protecting naturally occurring parasites, and threshold-driven applications of an insect pathogen. The experiments were designed to permit an assessment of pesticide use patterns and insect damage on crop yield and subsequent determination of crop value, costs of control programs, and net profits resulting from each approach.

In addition, a wide variety of insecticides has been applied to commercial celery, including acephate, azinphos-methyl, demeton, diazinon, endosulfan, methamidophos, naled, oxamyl, methomyl, and permethrin (Eickhoff et al. 1990). All of these compounds are frequently formulated as liquids with petroleum based solvent-carriers that rapidly evaporate following application (W. Jury, Soils and Environmental Sciences, University of California, Riverside, personal communication). Because celery is grown on >10,200 ha in California alone (Savio 1992), we were concerned that current pest control practices in commercial celery could be adding to air pollution. Therefore, the potential for air pollution resulting from solvent emission was estimated to provide comparative environmental benefits of an IPM program versus a chemical standard approach. Other environmental, public perception, and public health problems associated with some pesticides also exist (Trumble 1990) but are not addressed in this manuscript.

Materials and Methods

Field Station Studies. Experimental 0.4-ha plantings of celery ('Tall Utah' 5270-R) were established at the University of California's South Coast Research and Education Center in Orange County, California, during the fall seasons of 1992 and 1993. All plants were grown using local commercial practices, with the exception of treatments for insect control.

Three treatments were evaluated in a randomized complete block design. Experimental plots were 8 beds wide (2 rows per bed on 101-cm centers) by 20 m long with 4 replicates of each treatment. The 3 treatments included a chemical standard approach of preventative treatments (1.1 kg [AI]/ha of methomyl 1.9 L, [liquids, DuPont, Wilmington, DE] plus 0.22 kg [AI]/ha permethrin 3.2 EC, [emulsifiable concentrate, FMC, Philadelphia, PA]); a 2nd treatment of a low-insecticide use IPM approach (*Bacillus thuringiensis* at 2.47 kg [AI]/ha [Xentari, Abbott, Chicago, IL], and abamectin at 0.011 kg [AI]/ha [Merck, Raway, NJ]) as needed; and a control. All chemicals were applied by a tractor-mounted boom sprayer operated at 7.03 kg/cm^2 with 4 nozzles per row and carrier (H_2O) at 935 liters-ha. Disc-type cone nozzlés incorporated D-3 orifice discs, #25 cores and 50-mesh screens. All applications included a spreader sticker (Leaf Act 80A, PureGro, West Sacremento, CA).

Pesticides used in the chemical standard program were selected based on high use patterns from grower surveys (Eickhoff et al. 1990) and the pesticide use data maintained by the California Department of Pesticide Regulation (Wells 1995). Materials used in the IPM treatments were chosen by balancing control potential of lepidopterous pests [primarily *Spodoptera exigua* (Hübner)] with minimal disruption of the *Liriomyza* spp. parasites (Trumble 1985, Trumble et al. 1994). This is critical because naturally occurring parasites of *Liriomyza* spp. can provide effective control, whereas parasite disruption results in pest resurgence (Oatman and Kennedy 1976, Johnson et al. 1980, Trumble 1985).

In 1992, the celery was transplanted on 3 September, and harvested on 14 December. There were 4 applications of *B. thuringiensis* in the IPM treatment and 9 applications of methomyl and permethrin in the chemical standard treatment. Numbers of applications were based on average pesticide use data for California (Eickhoff et al. 1990). Application dates for the IPM treatment were 15 and 29 October, and 12 and 25 November. Application dates for the chemical standard treatment were 15, 22, and 29 October; 5, 12, 19, and 25 November; and 3 and 10 December.

In 1993, the celery was transplanted on 17 August and harvested on 30 November. There were 3 applications of *B. thuringiensis* in the IPM treatment and 9 applications of methomyl and permethrin in the chemical standard treatment. Application dates for the IPM treatment were 30 September, 6 October, and 3 November. Dates of applications in the chemical standard treatment were 30 September; 6, 14, 20, and 27 October; and 3, 10, 17, and 24 November.

In both years, *Liriomyza* spp. populations were evaluated by weekly counts of leafminer larvae and puparia in 4 (10.2 by 20.4 cm) trays per replicate, when the plants reached a suitable height (i.e., when they formed a canopy that the trays could fit beneath). Evaluations were conducted weekly beginning approximately 1 mo after planting. Evaluation of lepidopteran populations was based on weekly counts of 10 plants per replicate starting the week after planting. Determination of the need for pesticide applications in the IPM treatment was based on insect counts. For lepidopterous pests, averages exceeding 1 larva per 10 plants triggered treatment (J.T., unpublished data). Similarly, *Liriomyza* spp. populations exceeding 10 per tray were considered above threshold (Trumble 1985). However, this latter threshold was not exceeded in either year.

At harvest, the number of damaged plants found in 25 plants per replicate (100 per treatment) from the center 2 rows of each replicate was recorded. In addition, plants harvested from 15.25 m of row per replicate were classified by industry sizes (e.g., 2 = 2 doz plants per carton, 2.5 = 2½ doz plants per carton, 3 = 3 doz plants per carton, 4 = 4 doz plants per carton, hearts = 54 plants per carton).

Economic data on costs of applications were collected from several sources, including 8 commercial growers (Table 1). The values used in our anal-

Table 1. Cost estimates for production and harvest of celery

Costs/ha	Grower no.								
	1	2	3	4	5	6	7	8	Value[a]
Fixed									
Water	148.26	642.46	123.55	281.69	494.20	210.04	1,235.50	370.65	370.65
Seed	32.12	—	25.95	—	—	49.42	49.42	49.42	49.42
Transplants	2,883.67	2,125.06	2,479.52	1,976.80	2,070.70	1,976.80	2,601.96	2,335.10	2,223.90
Planting	639.99	457.14	644.61	420.07	667.17	741.30	679.53	506.56	494.20
Scouting	54.36	—	—	—	—	44.48	49.42	51.89	49.42
Other costs[b]	756.13	4,942.00	5,059.74	3,177.71	6,651.93	4,351.43	370.65	5,436.20	4,942.00
Pesticide use[c]	30.89	24.71	1,293.64	1,111.95	—	39.54	197.68	39.54	39.54
Pesticide[d]									
B. thuringiensis	24.71								
Methomyl	44.47								
Permethrin	56.33								
Variable (per carton)									
Harvest costs	4.10	3.60	3.75	—	3.60	4.22	1.80	3.45	3.70
Sales costs	Included	0.25	0.41	—	0.50	Included	0.80	0.25	0.40

[a] Values used in economic analyses presented in this manuscript.
[b] Includes fertilizer, land rent, overhead.
[c] Cost of tractor and driver to treat 1 ha, except for growers 3 and 4 who included costs of all applications and pesticides.
[d] Cost of material for application on 1 ha.

yses were based on these numbers, although averages or intermediate values were not used in every case if some growers included overhead in a particular category and others did not. Pesticide costs were provided by distributors; prices were based on the purchase of at least enough material to treat 4 ha (quantity discount). The Free On Board shipping prices on each harvest date were obtained from Market News Service, Sacramento, CA, for the southern (central/south coast) region. Because most growers currently employ scouts (generally for disease monitoring, but monitoring for insects in the chemical treated fields is also common to catch migrations and outbreaks), and the cost of scouting is minimal compared with the aggregate of other costs (Table 2), the expenses associated with scouting were assumed to be similar among the treatments. Finally, some insect-damaged plants could be salvaged for sale as hearts if the interior of the plant was not damaged. In the chemical standard and the IPM treatments, the conservative value of 90% salvageable was used, and in the control treatments only ≈20% of the damaged plants could be salvaged.

All values were standardized on a per hectare basis by scaling up yields from the research plots (1992, Table 3; 1994, Table 4). The economic analyses were conducted by determining the potential

Table 2. Costs of production and sales for celery in 1992 and 1993

Costs/ha	Control	IPM	Chemical standard
	Fixed costs		
Water	370.65	370.65	370.65
Seed	49.42	49.42	49.42
Transplants	2,223.90	2,223.90	2.223,90
Labor to plant	494.20	494.20	494.20
Scouting	49.42	49.42	49.42
Other costs	4,942.00	4,942.00	4,942.00
Tractor and driver[a]	0	39.54	39.54
Permethrin[b]	0	0	56.86
Methomyl[b]	0	0	44.48
B. thuringiensis[b]	0	24.71	0
Total 1992	$8,129.59	$8,386.57	$9,397.21
Total 1993	$8,129.59	$8,322.33	$9,397.21
	Variable costs		
Harvest/Carton	$3.70	$3.70	$3.70
Sales/Carton	$0.40	$0.40	$0.40
Total marketable cartons in 1992	1,865.10	3,039.70	2,999.50
Total marketable cartons in 1993	2,129.20	3,040.40	3,155.20
Total 1992	$7,646.91	$12,462.77	$12,297.95
Total 1993	$8,729.72	$12,465.64	$12,936.32

[a] Per hectare of application; 3 (1993) or 4 (1992) applications in the IPM treatment, 9 in the chemical standard treatment.
[b] Three (1993) or 4 (1992) applications of *B. thuringiensis* in the IPM treatment, 9 of methomyl + permethrin in the chemical standard.

Table 3. Harvest calculations for 1992 celery

Treatment	Size class	Total cartons	Marketable cartons[a]	$ per carton	Gross value
Control	2.0	352.2	172.6	$11.35	$1,958.94
IPM	2.0	616.4	548.6	$11.35	$6,226.64
Chem. std	2.0	369.8	344.0	$11.35	$3,903.89
Control	2.5	1,391.3	681.7	$10.35	$7,056.08
IPM	2.5	1,497.0	1,332.3	$10.35	$13,789.52
Chem. std	2.5	1,620.3	1,506.8	$10.35	$15,595.92
Control	3.0	951.0	466.0	$8.35	$3,891.13
IPM	3.0	845.4	752.4	$8.35	$6,282.28
Chem. std	3.0	880.6	818.9	$8.35	$6,838.16
Control	4.0	440.3	215.7	$7.35	$1,585.71
IPM	4.0	246.6	219.4	$7.35	$1,612.89
Chem. std	4.0	229.0	212.9	$7.35	$1,565.00
Control	Hearts	329.0	329.0	$9.00	$2,961.07
IPM	Hearts	186.9	186.9	$9.00	$1,682.53
Chem. std	Hearts	116.9	116.9	$9.00	$1,051.84
Control	All	3,463.9	1,865.1	—	$17,452.93
IPM	All	3,392.3	3,039.7	—	$29,593.86
Chem. std	All	3,216.5	2,999.5	—	$28,954.80

All values on a per hectare basis. Harvested 15 December 1992. All prices are average shipping point prices (Free on Board) for the day of harvest provided by Market News Services for the Southern District (central and southern California). Chem. std, chemical standard.

[a] Number of marketable cartons excludes insect-damaged plants, except for hearts. Cartons of hearts were salvaged from insect-damaged plants (see text).

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. Net profits were then calculated as the gross profit from each treatment minus the costs of pesticides and their application. Therefore, direct economic comparisons could be made between control strategies.

Grower Validation Trials. In 1995, a large scale validation trial was conducted in a commercial planting of 'G20' celery in Ventura County, California, on Gene Jackson Farms. The celery was transplanted on 23 August, and harvested on 19–20 December. There were 2 treatments arranged in a randomized complete block design; an IPM treatment and the grower's chemical standard treatment. No untreated control was incorporated into the design because the grower could not be expected to tolerate the probable economic loss. Each treatment was replicated 4 times, with each replicate consisting of 0.4 ha. Insect populations were monitored throughout the season (20 plants per replicate per week) using the same strategies as those used in the field station studies.

Under our supervision, all pesticide applications were made by the commercial company used by

Table 4. Harvest calculations for 1993 celery

Treatment	Size class	Total cartons	Marketable cartons[a]	$ per carton	Gross value
Control	2.0	274.8	159.4	$8.45	$1,183.38
IPM	2.0	374.7	326.0	$8.45	$2,420.55
Chem. std	2.0	499.7	464.7	$8.45	$3,449.47
Control	2.5	1,239.2	718.7	$7.45	$5,002.46
IPM	2.5	1,159.2	1,008.5	$7.45	$7,019.58
Chem. std	2.5	1,299.1	1,208.2	$7.45	$8,409.31
Control	3.0	1,432.4	830.8	$6.45	$4,806.00
IPM	3.0	1,365.7	1,188.2	$6.45	$6,873.70
Chem. std	3.0	1,299.1	1,208.2	$6.45	$6,989.32
Control	4.0	249.0	144.9	$6.45	$859.19
IPM	4.0	324.7	282.6	$6.45	$1,675.43
Chem. std	4.0	162.4	151.0	$6.45	$895.49
Control	Hearts	275.5	275.5	$9.00	$859.19
IPM	Hearts	235.1	235.1	$9.00	$1,675.43
Chem. std	Hearts	123.1	123.1	$9.00	$895.49
Control	All	3,471.6	2,129.2	—	$15,473.57
IPM	All	3,459.6	3,040.4	—	$21,870.95
Chem. std	All	3,383.4	3,155.2	—	$22,802.38

All values on a per hectare basis. Harvested 30 November 1993. All prices are average shipping point prices (Free on Board) for the day of harvest provided by Market News Services for the Southern District (central and southern California). Chem. std, Chemical standard.

[a] Number of marketable cartons excludes insect-damaged plants, except for hearts. Cartons of hearts were salvaged from insect-damaged plants (see text).

Table 5. Costs of production and sales for celery in 1995

Costs/ha	IPM	Ventura Grower
	Fixed costs	
Other fixed costs[a]	8,129.59	8,129.59
Tractor and driver[b]	158.16	158.16
Permethrin[c]	56.86	113.66
Methomyl[c]	0	133.44
B. thuringiensis[c]	333.55	244.63
Abamectin	208.50	625.50
Total	$8,886.66	$9,404.98
	Variable costs	
Harvest/Carton	$3.70	$3.70
Sales/Carton	$0.40	$0.40
Total marketable cartons	3,528.00	3,547.70
Total	$14,464.80	$14,545.57

[a] From Table 2.
[b] $39.54/ha of application, 4 applications.
[c] Per application per hectare: permethrin = $56.86; methomyl = 44.48; *B. thuringiensis* = variable rates, see text.

Table 6. Harvest calculations for 1995 celery

Treatment	Size class	Marketable cartons	$ per carton	Gross value
IPM	2.0	1,054.5	$8.45	$8,699.62
Chem. std	2.0	1,128.6	$8.45	$9,311.19
IPM	2.5	1,409.7	$7.45	$10,079.39
Chem. std	2.5	1,208.9	$7.45	$8,643.90
IPM	3.0	726.5	$6.45	$4,540.46
Chem. std	3.0	903.2	$6.45	$5,644.69
IPM	4.0	107.5	$6.45	$661.05
Chem. std	4.0	41.4	$6.45	$254.54
IPM	Hearts	231.0	$9.00	$2,079.35
Chem. std	Hearts	265.6	$9.00	$2,390.69
IPM	All	3,528.0	—	$26,059.88
Chem. std	All	3,547.7	—	$26,245.02

All values on a per hectare basis. Harvested 19–20 December 1995. All prices are average shipping point prices (Free on Board) for the day of harvest provided by Market News Services for the Southern District (central and southern California). Chem. std, Chemical standard.

Gene Jackson Farms. The insecticides used and the number of respective applications have been listed in the appropriate tables. Several weeks before harvest, a corporate decision was made to chemigate (22 November) the field with a wettable powder formulation of permethrin, presumably to insure elimination of any lepidopterous larvae before harvest. Because of the sprinkler line arrangement, no distinction could be made between the IPM and standard treatments. Thus, the IPM treatment did receive 1 unplanned application of insecticide (which was included in the economic analyses for both treatments as a pesticide cost without tractor and driver costs).

The plants were harvested by commercial harvesters who were unaware of the differences between treatments or the respective locations of the plots. Data were collected on the numbers of cartons of each size class of all plants harvested in each replicate (Table 6). All values were standardized on a per hectare basis by scaling up yields from the experimental plots.

A complete economic analysis comparing the 2 approaches was conducted using the same partial budget approach as described for the field station studies. On 1 occasion, when fungicides were applied to both treatments, the standard approach had insecticides included in this treatment and the IPM approach did not. To provide a conservative estimate of inputs, the cost of the tractor and driver was still charged to the IPM treatment, because the fungicides would have been applied regardless of insecticide use. All other fungicide applications were made at times when insecticides were being applied to both treatments.

Potential for Air Pollution. A conservative estimate of the release of solvents was made using the labeled amount of solvent in each pesticide formulation. For example, methomyl is 29% (AI) (S-methyl-N-[(methycarbamoyl)oxy] thioacetimidate), and 71% inert ingredients. The active ingredient is not volatile. Of the inert ingredients, 45% is cyclohexanone and 10% is methanol, and the remaining 16% was not specified or was not volatile. Permethrin is 25.6% nonvolatile active ingredients, 37% petroleum distillates, 20% aromatic petroleum solvents (≈10% xylene and ≈10% 1,2,4-trimethylbenzene), and some additional proprietary material, which may or may not contain volatile solvents. Thus, the values of 55% volatile solvents for methomyl and 57% for permethrin may be low, depending on what is in the proprietary or unspecified material. No information on solvent content was available for the abamectin formulation. However, because this material is produced by bacteria through a fermentation process, the assumption was made that solvent content was effectively zero. Wettable powders such as the *B. thuringiensis* formulation and the permethrin wettable powder were assumed to have no solvent release potential. The amount of solvent released into the atmosphere (ml/ha) was then calculated by multiplying the amount of formulated material used per hectare by the percent of the formulation that consisted of solvent. These calculations generated information intended for comparative purposes: to our knowledge no information is available correlating solvent release rates from agricultural operations with human or environmental health.

Results

Field Station Studies. Fixed costs were higher by approximately $1,000/ha during both years in the chemical standard treatment than in the IPM treatment (Table 2). This increase was entirely the result of the costs associated with application (tractor and driver) and pesticide purchase. The variable costs related to number of cartons harvested were similar for the chemical standard treatment (range, $12,297.95–$12,936.32/ha) and the IPM treatment (range, $12,462.77–$12,465.64/ha), but nearly $4,000/ha less in the control treatment

Table 7. Net profit information by control strategy and year

Treatment	Gross value	Costs of production	Net profit
		1992	
Control	$17,452.93	$15,776.49	$1,676.44
IPM	$29,593.86	$20,849.34	$8,744.52
Chem. std	$28,954.80	$21,695.16	$7,259.64
		1993	
Control	$15,473.57	$16,859.31	−$1,385.74
IPM	$21,870.95	$20,787.97	$1,082.98
Chem. std	$22,802.38	$22,333.53	$468.85
		1995	
IPM	$26,059.88	$23,351.00	$2,708.42
Chem. std	$26,245.02	$23,950.55	$2,294.47

Chem std, chemical standard.

(range, $7,646.91–$8,729.72/ha). This was caused by a nearly 1/3 reduction in the number of marketable plants in the control treatment.

In 1992, all treatments produced a similar number of cartons (range, 3,216.5–3,463.9/ha), but the control treatments suffered >45% loss caused by insect damage (primarily *S. exigua*). The losses were much less in the IPM treatment (10% loss) and in the chemical standard treatment (7% loss) (Table 3). Not surprisingly, the gross value of the crop in the control treatments was over $10,000/ha less than in the other treatments.

The harvest from the IPM treatment generated a gross value nearly $640/ha more than the chemical standard treatment (Table 3). This was primarily caused by the production of 204 more cartons per hectare in the highly valued size class 2. The availability of more hearts and cartons with size class 4 in the IPM treatment also helped balance the higher production from the chemical standard treatment in size classes 2.5 and 3.

In 1993, all treatments again produced a similar number of cartons (range, 3,383.4–3,471.6/ha). Losses caused by insect damage were nearly 40% in the control treatment, 12% in the IPM, and 7% in the chemical standard treatment. Therefore, the gross value of the crop in the control treatments was approximately $6,400 per hectare less than in the other treatments.

The numbers of marketable cartons were highest in the chemical standard treatment in all categories except size class 4 and hearts, which were highest in the IPM treatment. As a result, the gross value at harvest was $931/ha higher in the chemical standard treatment than in the IPM treatment. Because the prices growers were getting per carton were less in 1993 than in 1992 (Tables 3 and 4), the gross values of all treatments were nearly $7,000/ha less in 1993.

In both years, net profits were higher in the IPM treatment than in either the chemical standard or control treatments (Table 7). In 1992 and 1993, net profits in the IPM treatment were $1,485 and $614/ha higher, respectively, than the chemical standard treatment. Thus, even in years where celery prices were low, the IPM approach performed well. In 1993, the control treatment showed a net loss of $1,385/ha, demonstrating the risks of producing celery without insect control.

Grower Validation Trials. Fixed costs were higher by approximately $500 during 1995 in the chemical standard treatment used by the grower than in the IPM treatment (Table 5). As with the field station trials, this increase was caused by the costs associated with pesticide purchase. The variable costs related to number of cartons harvested were similar for the chemical standard treatment and the IPM treatment; the chemical standard treatment cost approximately $80 more.

The chemical standard treatment produced 74 additional cartons per hectare in size class 2, and 155 more cartons per hectare in size class 3 than the IPM treatment (Table 6). This surplus was balanced to a large extent by the higher production of cartons with size classes 2.5 (n = 200 more) and 4 (n = 66 more) in the IPM treatment. The gross value of the chemical standard ($26,245.02/ha) was only $185 greater than the gross profit from the IPM treatment ($26,059.88/ha). The actual amounts of celery in each size class that were lost to insects could not be calculated at harvest because the commercial harvest crews are paid by productivity, and the interference of data collection would result in salary losses. However, visual evaluation of the replicates after harvest suggested that <5% of the plants were not incorporated into cartons. Nonetheless, the gross value incorporates insect losses into the economic analyses.

Net profits were best with the IPM strategy (Table 7). This low pesticide use approach improved profits by better than $410/ha over the chemical standard treatment. This occurred despite the progressive policy of the grower regarding pesticide use; the chemical standard in this trial used ≈ 60% of what is commonly applied by the average California grower (Eickhoff et al. 1990). Thus, this validation test of the IPM approach was conservative; most growers would show greater economic benefits from adoption of the program.

The IPM strategy offers additional advantages that were not included in the economic analysis. Although some growers might be able to command a premium price for their celery as organically grown produce, the potential for human health concerns would be reduced with the use of compounds that are less toxic to mammals, and potential negative environmental impacts would be minimized with short-lived compounds, the primary advantage of the IPM strategy would be a reduction in pesticide resistance. In every case, the IPM program used fewer total applications, and required fewer applications of any specific insecticide (Table 8). Thus, the long-term economic advantages of using the IPM program probably are understated in these analyses.

Table 8. Solvent emissions for insecticide applications on celery

Treatment	Chemical applied	No. applications	Amt solvent	Total[a] emissions
		1992 and 1993		
IPM	*B. thuringiensis*	3 or 4	0	0.0
			Subtotal IPM	0.0
Chem. std	Methomyl	9	55%	7,806.2
	Permethrin	9	57%	4,504.0
		Subtotal chem. std		12,310.3
		1995		
IPM	*B. thuringiensis*[b]	3	0	0.0
	Permethrin[c]	1	0	0.0
	Abamectin[d]	1	—	—
			Subtotal IPM	0.0
Chem. std	*B. thuringiensis*[b]	4	0	
	Methomyl	3	55%	2,602.1
	Permethrin	1	57%	500.5
	Permethrin[c]	1	0	0.0
	Abamectin[d]	3	—	—
		Subtotal chem. std		3,102.6

All values on a per hectare basis. Chem std, chemical standard.
[a] In ml/ha of solvent; methomyl = 55% of 1,577 ml; permethrin at 57% of 878 ml.
[b] *B. thuringiensis* was applied at variable rates from 1.12–2.24 kg/ha.
[c] Permethrin applications using wettable powder rather than emulsifiable concentrate.
[d] Concentration of solvent in abamectin is unknown.

The program we evaluated is only one of many possible IPM strategies. Although this particular IPM program focused on pathogen use rather than application of conventional or new pesticide chemistries, alternative IPM approaches using the latter control strategies could be equally viable. In fact, alternative programs using a mix of chemistries could be desirable.

Potential for Air Pollution. All of the IPM treatments reported in this article used wettable powder formulations of insecticides and therefore resulted in no release of solvents from insecticide application (Table 8). No effort has been made to determine possible releases from the fungicides applied. In contrast, the chemical standard approach released >12,300 ml/ha (assuming solvents fully evaporated) in 1992 and 1993. In 1995, the chemical standard on the commercial operation emitted substantially less solvent at just >3,000 ml/ha. Therefore, even when compared with progressive chemical operations, the IPM strategy provided substantial savings in potential atmospheric emissions of solvents.

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