Efficacy and Economics of Three Fungicide Application Schedules for Early Blight Control and Yield of Fresh-Market Tomato

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ABSTRACT

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Three methods to schedule fungicide applications for control of tomato early blight were evaluated under coastal South Carolina conditions in spring 1994 and 1995. Weekly fungicide applications, applications based on visual scouting according to the South Carolina Tomato IPM Program, and applications called for by the TOM-CAST program with a threshold of 18 or 25 disease-severity values were compared with a nonsprayed control. Scouting and TOM-CAST reduced the number of fungicide applications to 4 and 6, respectively, compared with 10 weekly applications. In both years, all plots receiving fungicide had less blighted foliage than the nonsprayed control plots, which averaged 24.8% early blight severity at the end of the season. Area under the disease progress curve was lowest with the weekly or TOM-CAST schedules, intermediate with scouting, and highest with no fungicide. Mean yield of extra-large (≤ 70 mm diameter) mature green and pink fruit was 2.9 t/ha (28%) greater ($P \leq 0.05$) with the weekly or TOM-CAST schedules than with scouting or no fungicide. Crop value and net return were not significantly affected by fungicide applications. Treatment costs (fungicide scheduling plus application costs) were highest for weekly applications but averaged 26 to 46% less for scouting and TOM-CAST. Early blight severity at the end of the season was lower on the tolerant cultivar Mt. Pride than on the susceptible cultivar Sunny in 1995 but not in 1994. TOM-CAST could be implemented by growers of fresh-market, mature green tomato in the coastal plain of the southeastern United States to effectively manage early blight.

Additional keywords: *Alternaria solani*, chlorothalonil, mancozeb

In the southeastern United States, fresh-market tomato (*Lycopersicon esculentum* Mill.) is produced for harvest at the mature green and pink stage in Florida, coastal South Carolina, and the Delaware–Maryland–Virginia peninsula, while vine-ripe production is concentrated in the mountains of western North Carolina and eastern Tennessee. South Carolina's tomato crop was valued at $40.3 million in 1993, with a 7-year (1985 to 1991) average value of $29 million, which makes tomato the most valuable vegetable crop produced in the state (29). Fresh-market tomato production in South Carolina is concentrated in the coastal counties of Charleston and Beaufort, where fresh-market tomato is grown in fumigated soil under polyethylene mulch with drip irrigation and staking. Fungicides account for 3% of the preharvest production costs, which average $4,745/ha for this system.

Early blight, caused by *Alternaria solani* Sorauer, is one of the most serious foliar diseases of tomato throughout the eastern United States. Early blight will develop when leaves remain wet for at least 3 h at 21 to 25°C (17), but conidia will germinate at temperatures up to 34°C or when the relative humidity is $\geq 90\%$ (27). Although several tomato cultivars recently developed in North Carolina are moderately resistant to *A. solani* (2,15,16), most growers continue to rely on protectant fungicides to suppress early blight.

The South Carolina Tomato Association manages the tomato IPM program (SC-IPM) developed by Clemson University Extension personnel in the late 1970s. This program is one of two long-established tomato IPM programs in the country (23). Fields are scouted once or twice per week for insects and diseases. A threshold of 3 to 6% diseased leaf surface area (disease severity) is used to trigger fungicide applications for early blight. This threshold was based on field observations of early blight epidemics and information that tomato foliage becomes more susceptible to *A. solani* as it ages (11). However, many growers are unwilling to risk development of early blight epidemics and often choose to apply protectant fungicides on a weekly basis, beginning 2 weeks after transplanting. The effectiveness of the SC-IPM scouting program for management of early blight has not been evaluated previously. The economics of fungicide use, including the cost of fungicide scheduling, and risk of yield loss likely will influence growers' decisions to adopt modified fungicide application schedules.

FAST (Forecasting Alternaria Solani on Tomato) is a computer program developed for scheduling fungicide applications to control early blight based on environmental conditions favorable for disease development (17). An adaptation of this program known as TOM-CAST, which uses hours of leaf wetness and associated temperatures (20,21), is used extensively in commercial tomato production in Ontario (3,20,21) and was tested on fresh-market tomato in Pennsylvania (15) and Alabama (28). It also has been evaluated for scheduling fungicide applications for early blight, Septoria leaf spot, and anthracnose fruit rot on processing tomato in the midwestern (5,6,25) and northeastern (8) United States. In a recent study of early blight epidemics on 13 fresh-market tomato cultivars, 11 cultivars had significantly less diseased leaf area at the end of the season in plots that received chlorothalonil applications scheduled with TOM-CAST than in nonsprayed plots (3). TOM-CAST has consistently reduced the amount of fungicide applied to tomato crops by up to 50% compared with weekly sprays (5,6,8,15,25,28). However, TOM-CAST has not been compared with spray programs based on weekly visual scouting, such as the SC-IPM program.

The objective of this study was to compare early blight development, marketable yield, cost of fungicide applications, and economic return for fresh-market tomato managed according to different fungicide schedules (weekly, visual scouting, TOM-CAST, or not treated). Comparing TOM-CAST and SC-IPM scouting was of special interest under coastal South Carolina conditions.

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MATERIALS AND METHODS

Field experiments. Plots were located at the Coastal Research and Education Center, Charleston, South Carolina, in Yonges loamy fine sand (Typic Albaquults). Soil was shaped into raised beds 1.8 m apart, fumigated with 98% methyl bromide–2% chloropicrin at 242 kg/ha, fertilized with 15-0-15 (N-P-K) at 1,345 kg/ha, and covered with black polyethylene mulch. Tomato transplants cv. Sunny (susceptible to early blight) and Mountain Pride (tolerant to early blight [15]) from The Plant Farm, Sarasota, FL, were set 0.46 m apart on 4 April 1994 and 13 to 14 April 1995. Plants were drip-irrigated, staked, pruned, and tied according to local horticultural practices (4). No herbicides were used. Insects were controlled with esfenvalerate (Asana, 0.056 kg/ha) and methomyl (Lannate, 0.50 kg/ha) applied to all plots five and zero times in 1994, respectively, and three and two times in 1995, respectively. Copper (Tenncop 5E, 0.18 kg/ha) was applied to all plots twice each year (2 and 8 June 1994 and 12 and 21 June 1995) after symptoms of bacterial spot were detected.

The experimental design was a split-plot with fungicide application schedule as the whole plot and cultivar as the subplot. Subplots, four rows wide (1.8-m spacing) and 14.3 m long, were separated by one row of rye on the sides but were contiguous within rows. The fungicide application schedules were: none = no fungicides applied; SC-IPM = fungicides applied beginning when early blight severity of 3 to 6% was detected during weekly scouting, and every week afterward when this level of disease was detected; TOM-CAST-18 = environmental monitoring initiated 2 weeks after transplanting, first fungicide applied when cumulative daily disease-severity values (DSV) reached 18 and whenever this threshold was reached thereafter (17); TOM-CAST-25 = same as TOM-CAST-18 but with a threshold of 25 DSV, tested in 1995 only; and weekly = fungicides applied every 7 days beginning 2 weeks after transplanting. Leaf wetness and temperature data for TOM-CAST were recorded with a CR-10 micrologger (Campbell Scientific, Logan, UT) located in a grassy area immediately adjacent to the plots. A threshold of 18 DSV was chosen initially based on previous reports (7,21,25,28). In all treatments, mancozeb (Manzate 200DF, 1.26 and 2.52 kg/ha during weeks 3 to 5 and weeks 6 to 9 after transplanting, respectively) was applied until ≥5 days before the first harvest, when chlorothalonil (Bravo 720, 1.73 kg/ha in 1994 and Bravo Ultrex, 1.66 kg/ha in 1995) was substituted according to local practices because of cost and the 5-day preharvest interval for mancozeb on tomato. Fungicides were applied in 280 liters of water per hectare with a boom sprayer operated at 276 kPa with seven cone nozzles (Teejet 23601, Spraying Systems Co., Jacksonville, FL) per row, three on each side spaced 0.35 m apart and one over the row.

Early blight severity was rated weekly beginning 2 weeks after transplanting on one six-plant (2.7-m) section in both center rows in all plots with a modified Horsfall-Barratt scale of 1 = 0%, 2 = 1 to 10%, 3 = 11 to 30%, 4 = 31 to 70%, 5 = 71 to 90%, and 6 = 91 to 100% (R. Latin and S. Johnston, *unpublished*). All mature green and pink fruit on six plants (2.7 m of row) in one randomly chosen center row in each

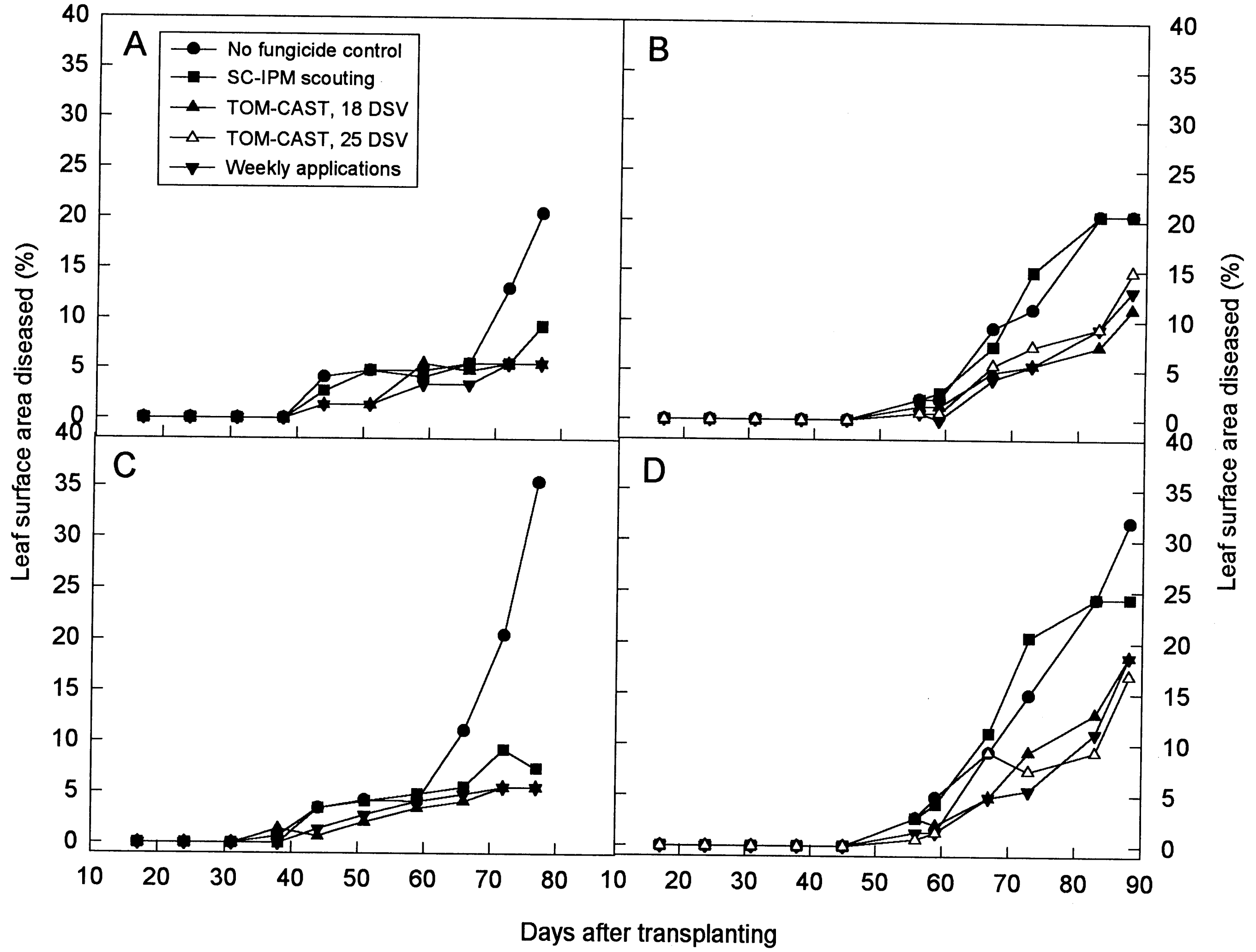

Fig. 1. Early blight progress curves for tomato (**A**) cultivar Mt. Pride, 1994; (**B**) Mt. Pride, 1995; (**C**) Sunny, 1994; and (**D**) Sunny, 1995. Protectant fungicides were applied according to four schedules in 1994 and five schedules in 1995. Each value is the mean of four replicate plots.

plot were harvested on 14, 21, and 28 June 1994; fruit were harvested from three plants in both center rows in each plot on 27 June and 5 and 11 July 1995. Fruit were graded into those of marketable and unmarketable quality, counted, weighed, and separated into medium (≤57 mm diameter), large (≤63 mm), and extra large (≤70 mm) sizes (1,19).

Economic and statistical analysis. Fungicide costs for mancozeb and chlorothalonil were estimated as $6.17 and $17.97 per kg, respectively. The application cost per hectare of $8.44 was calculated from $7.16 for operation and upkeep of spray equipment and $1.28 for labor (at $5.00/h). No additional cost for scheduling was associated with the nonsprayed and weekly treatments. The grower cost per hectare for professional scouting is $61.73, as set by the SC Tomato Association. TOM-CAST equipment costs an average of $2,615 ($2,735 from Campbell Scientific, Logan, UT, and $2,495 from Pest Management Supply, Inc., Hadley, MA) plus $1,080 for replacement components during the 20-year life expectancy of the micrologger. Labor to maintain and operate the equipment was estimated to be $250 per year. On a per hectare basis, the equipment and operation cost is $96.61 for a 90-ha operation, $4.83 per hectare per year for 20 years.

Crop value was calculated for each size of mature green and pink tomato at each harvest and summed. Returns for each treatment and cultivar combination were calculated from total crop value minus fungicide scheduling, application, and material costs, a preharvest cost of $4,595/ha, average harvest cost of $14,753/ha, and a fixed cost of $2,020/ha.

Analysis of variance for a split-plot design was done with PROC GLM of SAS (SAS Institute, Cary, NC, release 6.10). Mean percent leaf area diseased for each plot, averaged across rows, was calculated from the midpoint of the percent range represented by the Horsfall-Barratt values. Area under the disease progress curve (AUDPC) was calculated from disease severity ratings with standard iterative procedures (26). All data sets were tested for equality of variance and normality; final disease severity and AUDPC were transformed with the base-10 logarithm or square root before analysis. Disease progress curves were plotted for each replicate of each treatment and cultivar combination to determine empirically the day after transplanting on which early blight severity reached 5%. A separate split-split-plot analysis of variance with year as the whole plot, treatment as the subplot, and cultivar as the sub-subplot was done on data combined over the 2 years. Treatment means were compared with *t* tests, Fisher's protected least significant difference, or preplanned, single-degree-of-freedom, orthogonal contrasts. Pearson correlation coefficients and linear regression were used to determine the relationships between disease severity or AUDPC and fruit yield.

RESULTS

Early blight epidemics. Early blight developed slowly in spring 1994 and 1995, when precipitation was below the 120-year average in April and May of both years. However, epidemics increased rapidly in nonsprayed plots after frequent rains began in June (Fig. 1). DSV were highly correlated with hours of leaf wetness ($r = 0.87$, $P = 0.0001$ for both years), but not with the daily maximum, minimum, or mean air temperature or rainfall.

In 1994, the nonsprayed, SC-IPM, TOM-CAST-18, and weekly treatments received a total of zero, four, six, and 10 fungicide applications, respectively. Based on the cumulative DSV recorded, the TOM-CAST with a threshold of 25 DSV would have been sprayed five times. Early blight development, as measured by AUDPC and disease severity at the end of the season, was significantly greater in nonsprayed plots than in sprayed plots (Table 1). There were no significant differences in early blight severity between the TOM-CAST-18 and weekly treatments. In the SC-IPM treatment, early blight severity reached 5% sooner and AUDPC was greater than in the TOM-CAST-18 and weekly treatments; however, final disease severity in this treatment did not differ from the other two sprayed treatments. Once fungicide applications were begun in the SC-IPM treatment, early blight development appeared to slow (Fig. 1).

In 1995, the nonsprayed, SC-IPM, TOM-CAST-18, TOM-CAST-25, and weekly treatments received a total of zero, four, five, seven, and 10 fungicide applications, respectively. The nonsprayed and SC-IPM plots reached 5% early blight severity at 59 days after transplanting. At this point in the growing season, the SC-IPM treatment had not received any fungicide, while weekly plots had been sprayed six times. Weekly fungicide applications delayed early blight development by 8 days compared with the nonsprayed and SC-IPM treatments (Table 1). AUDPC and early blight severity at the end of the season were lower in the weekly and both TOM-CAST treatments, which received more and earlier fungicide applications than did the other two treatments. There were no differences between TOM-CAST treatments with thresholds of 18 and 25 DSV.

Comparison of years. The four treatments tested in both years were compared with a split-split-plot analysis of variance. In both years, the threshold to initiate fungicide applications was reached 60 days after transplanting in the SC-IPM treatment (Table 1). Likewise, the first application of mancozeb to the TOM-CAST-18 plots was made 1 week after the first application to the weekly plots in both years.

Early blight epidemics reached 5% severity earlier ($P \leq 0.05$) in the nonsprayed and SC-IPM plots in 1994 than in 1995 by an average of 13 and 6 days, respectively (Table 1). Progress of epidemics in the

Table 1. Comparison of early blight epidemics on tomato treated with protectant fungicides applied according to different scheduling treatment in 1994 and 1995[t]

	First fungicide application[u]		Days to 5% disease severity[u]		Final disease severity (%)[v]		AUDPC[w]	
Treatment	**1994**	**1995**	**1994**	**1995**	**1994**	**1995**	**1994**	**1995**
None	None	None	46.6 a[x]	59.4 a	26.7 a	21.7 a	757.2 a	416.1 a
SC-IPM	59	60	53.0 a	59.1 a	8.7 b	24.3 a	452.3 b	396.3 a
TOM-CAST 18 DSV	23	25	61.3 b	63.4 ab	6.5 b	14.3 b	304.9 c	212.6 b
TOM-CAST 25 DSV	26[y]	28	n.t.[z]	64.5 ab	n.t.	15.5 b	n.t.	220.0 b
Weekly	17	18	65.6 b	67.6 b	6.5 b	12.4 b	293.8 c	171.8 b
Alpha			0.05	0.01	0.01	0.05	0.05	0.01

[t] Averaged across two cultivars (Mt. Pride and Sunny).

[u] Days after transplanting.

[v] Disease severity at 77 and 88 days after planting in 1994 and 1995, respectively. Disease severity was transformed with $\log_{10}$ before analysis of variance. Values shown are back-transformed means.

[w] Area under the disease progress curve. AUDPC was transformed with $\log_{10}$ and square root in 1994 and 1995, respectively, before analysis of variance. Values shown are back-transformed means.

[x] Means within a column followed by the same letter are not significantly different, Fisher's protected least significant difference.

[y] Estimated from cumulative disease-severity values.

[z] Not tested in 1994.

TOM-CAST-18 and weekly plots did not differ between years. Cultivar had no effect on epidemic progress at this point in the growing season. Final disease severity was higher in 1995 than in 1994 for the three sprayed treatments, but did not differ between years for the nonsprayed treatment (treatment × year, *F* significant, $P = 0.003$). In 1994, the SC-IPM treatment had the same amount of early blight at the end of the season as did the other two sprayed treatments, which was less than the nonsprayed treatment. However, in 1995, SC-IPM had as much early blight as the nonsprayed treatment and significantly more than TOM-CAST-18 and weekly. There was no treatment by year interaction for AUDPC. The TOM-CAST-18 treatment, which had a mean AUDPC of 259.6, was as effective as weekly sprays (237.9) in reducing early blight over the entire season. The SC-IPM treatment (439.5) was less effective than the other two sprayed treatments but more effective than the nonsprayed treatment (589.5) ($P \le 0.01$).

Although the two cultivars did not differ in 1994, in 1995, early blight severity at the end of the season and AUDPC were significantly ($P \le 0.001$) lower on Mt. Pride than on the susceptible cultivar Sunny (Table 2). For both cultivars, final disease severity was higher but AUDPC values were lower in 1995 than in 1994.

Yield and value. Weight of marketable, extra-large, mature green and pink fruit was 38% greater ($P = 0.04$) for both cultivars in fungicide-treated plots (mean of 14.7 t/ha) than in nonsprayed plots (10.7 t/ha) in 1995, but not in 1994 (Table 3). Yield of marketable fruit of all three sizes averaged across cultivars and years was greater in plots sprayed weekly or with TOM-CAST-18 than in the SC-IPM or nonsprayed plots (Table 4). Total yield (all marketable plus cull fruit) did not differ significantly among treatments, and there was no treatment by cultivar interaction (data not shown). Mean marketable weight of mature green and pink fruit of Mt. Pride (38.3 ± 1.83 t/ha [standard error]) was significantly less ($P < 0.01$) than that of Sunny (43.6 ± 1.71 t/ha) averaged across the 2 years. Average weight of individual mature green fruit, 204 and 195 g, 145 and 135 g, and 104 and 102 g for extra-large, large, and medium fruit sizes in 1994 and 1995, respectively, did not differ among treatments or between cultivars. Number of cull fruit with Alternaria fruit rot was <1%. Weight (Fig. 2) and number ($r = -0.83$, $P = 0.003$) of extra-large marketable pink and green fruit were negatively correlated with AUDPC in 1995. Lowest yields for both cultivars were in the nonsprayed plots. Weight of marketable mature green fruit of all three sizes also decreased linearly with increasing AUDPC ($r = -0.81$, $P = 0.005$). There was no correlation between yield and AUDPC in 1994.

Average price for mature green and pink tomato (f.o.b. [free on board] farm) was less during the 1994 harvest periods, \$8.00 per 11.3-kg box (range \$7.00 to \$9.00), than in 1995, \$10.55 (\$4.50 to \$16.00) per 11.3-kg box. Because of this price difference, crop value of marketable fruit and net return per hectare in 1995, \$42,648 ± 1,872 and \$21,106 ± 1,866, respectively, were greater than in 1994, \$25,387 ± 919 and \$3,843 ± 923 respectively (*F* significant, $P < 0.01$). Fungicide applications and cultivar did not significantly affect crop value or net return (Tables 3 and 4). Treatment costs (fungicide scheduling plus applications) were <1% of total crop value.

Applying fungicides according to SC-IPM scouting or TOM-CAST with a 25-DSV threshold minimized the amount of fungicide active ingredient applied, the fungicide application cost, and the total treatment cost compared with weekly sprays. The five scheduling treatments ranked most to least expensive, based on

Table 2. Comparison of early blight epidemics on tolerant (Mt. Pride) and susceptible (Sunny) tomato cultivars in 1994 and 1995

	Final disease severity (%)[w]		AUDPC[x]	
Cultivar	**1994**	**1995**	**1994**	**1995**
Mt. Pride	9.6 aA[y,z]	15.8 aB	396.1 aA	260.7 aB
Sunny	10.3 aA	23.0 bB	442.1 aA	350.5 bB

[w] Disease severity at 77 and 88 days after planting in 1994 and 1995, respectively. Disease severity was transformed with $\log_{10}$ before analysis of variance. Values shown are back-transformed means.

[x] Area under the disease progress curve. AUDPC was transformed with $\log_{10}$ before analysis of variance. Values shown are back-transformed means.

[y] Cultivar means by year within a column are not significantly different when followed by the same lowercase letter, *t* test, $P \le 0.002$.

[z] Year means by cultivar within a row are not significantly different when followed by the same uppercase letter, *t* test, $P \le 0.001$.

Table 3. Cost of scheduling and applying fungicides for control of early blight, yield, value, and return of marketable extra-large mature green and pink tomato fruit in 1994 and 1995

		Applications[s]									
		Mancozeb		Chlorothalonil	Total fungicide	Cost of applic.	Cost of scheduling	Total cost	Yield of extra-lg. fruit	Value of extra-lg. fruit	Return
Year	**Treatment**	**1.3 kg/ha**	**2.5 kg/ha**	**1.7 kg/ha**	**(kg a.i./ha)**	**(\$/ha)[t]**	**(\$/ha)**	**(\$/ha)[u]**	**(box/ha)[v]**	**(\$/ha)**	**(\$/ha)[w]**
1994	None	0	0	0	0	0	0	0	925	8,072	8,072
	SC-IPM	0	1	3	7.6	147.81	61.73	209.54	752	6,552	6,342
	TOM-CAST-18	1	3	2	12.2	189.30	4.83	194.13	917	7,929	7,735
	TOM-CAST-25	1[x]	2[x]	2[x]	9.7	155.17	4.83	160.0	n.t.[y]	n.t.	n.t.
	Weekly	3	4	3	19.0	296.73	0	296.73	849	7,372	7,075
1995	None	0	0	0	0	0	0	0	944[z]	10,738	10,738
	SC-IPM	0	2	2	8.4	139.65	61.73	201.38	1,081	12,070	11,869
	TOM-CAST-18	2	2	3	12.7	217.92	4.83	217.62	1,461	16,512	16,294
	TOM-CAST-25	1	3	1	10.5	144.59	4.83	150.16	1,174	13,418	13,268
	Weekly	4	4	2	18.6	276.55	0	276.55	1,506	16,998	16,722

[s] Mancozeb at 1.3 and 2.5 kg/ha was applied during weeks 3 to 6 and 7 to 9 after planting, respectively; chlorothalonil was applied during weeks 10 to 12 (5 days before and during the harvest period).

[t] Cost of fungicide applications was calculated from a cost of \$6.17/kg for mancozeb, \$17.97/kg for chlorothalonil, \$7.16 for operation and upkeep of spray equipment, and \$1.28 for labor.

[u] Cost of fungicide applications plus scheduling.

[v] Number of 11.3-kg boxes per hectare, averaged across the two cultivars.

[w] Crop value – treatment cost.

[x] Estimated from cumulative disease-severity values.

[y] Not tested in 1994.

[z] Single-degree-of-freedom contrast of nonsprayed with sprayed treatments significant at $P = 0.04$.

total treatment costs, were weekly > TOM-CAST-18, SC-IPM > TOM-CAST-25 >> none (Fisher's protected LSD, $P \leq 0.05$) (Table 3). TOM-CAST-25 cost only 46% as much as weekly sprays. Averaged across the 2 years, fungicide application costs for SC-IPM ($144/ha), TOM-CAST-25 ($150/ha), and TOM-CAST-18 ($204/ha) were lower ($P \leq 0.05$) than the cost for the weekly treatment ($287/ha). Similarly, the total amount of fungicide active ingredient applied per hectare was lower ($P \leq 0.01$) for SC-IPM and TOM-CAST-25 than for TOM-CAST-18, which was significantly lower than weekly applications. The SC-IPM, TOM-CAST-25, and TOM-CAST-18 schedules reduced fungicide load by 57.5, 46.3, and 33.8%, respectively, compared with the weekly schedule.

DISCUSSION

In 2 years of field trials on fresh-market tomato harvested at the mature green and pink stages, scheduling fungicide applications with TOM-CAST controlled early blight epidemics as effectively as weekly sprays. This is consistent with previous reports on vine-ripe fresh-market and processing tomato (5,6,8,15,25,28). Early blight epidemics progressed similarly in both years. This was not surprising since environmental conditions, particularly rainfall patterns, were almost parallel in 1994 and 1995. Consequently, timing of fungicide applications was identical between years for both TOM-CAST thresholds and SC-IPM scouting. Although TOM-CAST-25 was not tested in the field in 1994, the cumulative DSV data from 1994 and the close agreement among all fungicide treatments in 1994 and between TOM-CAST-18 and -25 in 1995 indicate strongly that this treatment would not have differed from weekly sprays or TOM-CAST-18 in 1994.

The main difference between SC-IPM and the other fungicide schedules was that fungicide applications were initiated later in the season in the SC-IPM treatment, based on a threshold of 3 to 6% early blight severity. However, delaying fungicide applications resulted in a higher final disease level and lower yield of extra-large fruit than did application of sprays throughout the season on a weekly basis or according to TOM-CAST predictions. This approach represents a risk to the grower, namely, that early blight may not be controllable late in the growing season if above-average precipitation leads to environmental conditions conducive to early blight and simultaneously hampers fungicide applications. Delaying fungicide applications until an epidemic of early blight is underway may not be the most appropriate management strategy for a polycyclic disease. In Pennsylvania, delaying fungicide applications on cultivar Sunny until 1% of the foliage was affected with early blight did not increase final disease severity compared with full-season applications, but using a threshold of 3% diseased foliage increased severity by the end of the season and reduced yield of vine-ripe fruit (12–14). Lowering the SC-IPM threshold to 1 to 3% affected foliage may be advisable to improve consistency in early blight control.

Yield losses from early blight are due to reduced plant productivity as photosynthetic leaf area is lost, as well as to sunscald and premature ripening and decay of ripe fruit (6). Harvesting fruit at the mature green and pink stages could partially account for the modest yield response observed in this study, since no fruit were lost to Alternaria fruit rot and the life of the crop was shortened compared with vine-ripe production (28). Foliar symptoms of early blight were not severe enough in either year to reduce total marketable yield of mature green and pink fruit; however, yield of extra-large fruit, the size that consistently brings the highest price to growers, was reduced in plots receiving ≤4 fungicide applications. In other studies, yields of extra-large tomato fruit were reduced by early blight (14), target spot (19), and bacterial spot (22). However, in Ontario, total marketable yield of mature green fruit on Sunny and 12 other cultivars was not increased over the nonsprayed control by chlorothalonil applied according to TOM-CAST scheduling for early blight control (3). The effects of early blight on tomato yield are influenced by time of disease onset in relation to fruit set and rate of epidemic progress (3,14,27), although no quantitative yield-loss relationship has been reported in the literature for mature green fruit. If early blight epidemics had begun to increase rapidly earlier in the season, the yield reduction observed in this study may have been greater, based on the significant negative linear relationships between AUDPC and yield. For example, yield of extra-large fruit in plots sprayed weekly (AUDPC of 238) was increased by an estimated 76% over yield of nonsprayed plots (AUDPC of 590) (Fig. 2). Weekly applications of chlorothalonil to control early blight increased marketable yields of vine-ripe fruit on Sunny by 22% in Pennsylvania (13) to 87% in Tennessee (2). Weekly applications of chlorothalonil also prevented yield loss of 30 to 43% by *Corynespora cassiicola* on mature green tomato in southern Florida (19).

The amount of fungicide active ingredient applied per hectare was reduced in all three modified spray programs compared with weekly sprays. SC-IPM scouting and TOM-CAST with a threshold of 25 DSV reduced fungicide load by 48%, which is consistent with the results of previous studies that included TOM-CAST-25 (5,6,8). A reduction in pesticide use is likely to have societal benefits not addressed in this study. Ragsdale and Sisler (24) suggested that the public is more likely to accept some level of pesticide use if growers participate in a recognized IPM program, such as the SC-IPM program, the Florida tomato IPM program (23), or the midwestern TOM-CAST implementation program (6).

Growers who sprayed weekly to prevent early blight epidemics applied more fungicide than was necessary to manage this disease in South Carolina in 1994 and 1995. However, another serious tomato disease, bacterial spot, occurs each year in coastal areas of the southeastern United States (22). Ethylene-bisdithiocarbamate (EBDC) fungicides such as mancozeb are routinely tank-mixed with copper com-

Table 4. Mean yield, value, and net return for mature green and pink fruit from field experiments in 1994 and 1995

Treatment	Yield of extra-lg.[w] fruit (box/ha)[x]	Value of extra-lg.[w] fruit ($/ha)	Yield of marketable fruit (box/ha)[x]	Value of marketable fruit ($/ha)	Net return ($/ha)[y]
None	934 b[z]	9,405	3,499	32,447	11,079
SC-IPM	917 b	9,311	3,399	31,946	10,372
TOM-CAST-18	1,189 a	12,220	3,839	35,594	14,020
Weekly	1,178 a	12,185	3,753	36,083	14,428

[w] Fruit ≤70 mm in diameter.

[x] Number of 11.3-kg boxes per hectare, averaged across the two cultivars.

[y] Value of marketable fruit − (total treatment cost from Table 2 + other preharvest variable costs [$4,595] + harvest costs [$14,753] + fixed costs [$2,020]).

[z] Means within a column followed by the same letter are not significantly different, *t* tests, $P \leq 0.05$.

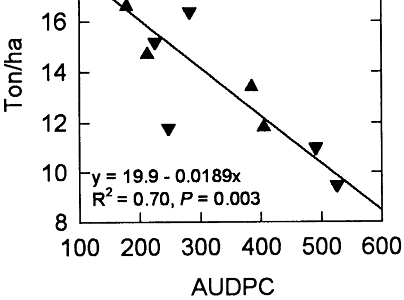

Fig. 2. Correlation of marketable yield of extra-large mature green and pink fruit with area under the disease progress curve in 1995. Each value is the mean of four replicate plots. Yield data were summed over three weekly harvests.

pounds to enhance control of bacterial spot over copper applications alone (9,18), although the synergistic effect is not apparent in every season (10). Applications of mancozeb plus copper scheduled with TOM-CAST would not be frequent enough to prevent yield loss by bacterial spot (9). Improved management of bacterial spot must be addressed before use of EBDC fungicides will decrease substantially on fresh-market tomato in coastal South Carolina. Nevertheless, the rate of mancozeb could be reduced by at least two-thirds when applications are not needed for early blight control and still enhance the effectiveness of copper. A combination product on the market that contains 45.8% copper oxychloride–4.5% manganese-EBDC–27% chlorothalonil effectively reduces bacterial spot.

Because total costs for all treatments were a low percentage of the total investment in a fresh-market tomato crop, efficacy, yield, net return, and environmental impact are likely to be important considerations to growers choosing a fungicide scheduling program. Growers likely will not eliminate fungicide applications for early blight control as long as the potential for yield loss exists because of the high preharvest cost for tomato production. TOM-CAST could be implemented by growers of fresh-market, mature green tomato in the coastal plain of the southeastern United States to manage early blight successfully. Disease control, yield, crop value, and net return did not differ significantly between TOM-CAST and weekly sprays, whereas the amount of fungicide applied was lower. Growers who initially question the reliability of TOM-CAST scheduling could begin with a threshold of 18 DSV, then adopt 25 DSV in subsequent years as confidence in the program grows based on personal experiences.

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