Losses in Fresh-Market Tomato Production in Florida Due to Target Spot and Bacterial Spot and the Benefits of Protectant Fungicides

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ABSTRACT

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Three large-scale field tests were conducted under commercial growing conditions in southwestern Florida to quantify yield losses associated with foliar diseases of fresh-market tomatoes, document the benefits of protectant fungicides, and establish a protocol to be used in making yield-loss assessments for fresh-market tomatoes. The benefits of protectant fungicides were amply demonstrated in two of three experiments. Marketable and extra-large fruit yields were reduced 30 and 43% in these tests, respectively, when no fungicides were used. Net returns on investment were $7,800 to $14,800/ha greater in plots treated with chlorothalonil than in control plots. Much of the loss in marketable yield was due to direct damage to fruit by the target spot fungus. As much as two-thirds of the fruit had to be discarded in no-spray plots because of blemishes from target spot. Tank-mix sprays of copper-mancozeb provided good early season control of bacterial spot, but there was no correlation between bacterial spot damage levels and yield or monetary losses. Little return on investment in protectant fungicides was recorded where target spot was not a factor in the third experiment, even though low to moderate levels of bacterial spot were present.

Risk-benefit analysis is an increasingly important activity within the Environmental Protection Agency (EPA). In this analysis, attempts are made to measure the health and environmental risks associated with a pesticide use, as well as the benefits accruing to producers and the consuming public from effective and economic pest management. In the past, benefits of pesticides, including many widely used fungicides, were based on "expert opinion." This term was applied to the estimates by extension specialists and other professionals of yield and dollar losses mitigated by applications of registered fungicides. In recent litigation, written documents containing these estimates were ruled inadmissible as hearsay (6). Even when given in direct testimony, these estimates have been deemed a poor substitute for data collected in specific loss experiments gathered under actual grower conditions. According to the General Accounting Office (6), a major drawback in these judicial proceedings has been the lack of consistency among scientists performing this work in both disease ratings and yield loss measurements. Large-scale experiments, conducted under commercial conditions over several years, are needed to quantify control benefits.

In the spring of 1992, a joint EPA/USDA panel was established to develop protocols for meaningful disease loss experiments. Tomato (*Lycopersicon esculentum* Mill.) was chosen as the model crop for the proposed studies, because it is produced on substantial hectarage in many different areas of the country. Tomato is the most important vegetable crop in Florida, with a value of $728 million on 20,770 harvested hectares (5). A number of foliar diseases threaten the state's tomato production (14). Routine applications of fungicide (bactericide) are especially important for management of bacterial spot (2), caused by *Xanthomonas campestris pv. vesicatoria*, and target spot, caused by *Corynespora cassiicola* (Berk. & M.A. Curtis) C.T. Wei (9). The objectives of this study were to (i) gather information on yield, quality, and monetary losses associated with foliar diseases of fresh-market tomatoes in Florida in a commercial setting, with emphasis on bacterial spot and target spot, (ii) document clearly the benefits of registered, protectant fungicides, and (iii) establish a protocol for measuring yield losses due to foliar diseases in fresh-market tomatoes. A preliminary portion of this work has been published (11).

MATERIALS AND METHODS

Three large-scale field experiments were conducted on a commercial farm near Immokalee, Florida. In each experiment, five treatments were replicated five times in a randomized complete block experimental design. Plots were established by setting 6-week-old tomato transplants into an Immokalee fine sand soil through holes punched in the plastic mulch used to cover raised planting beds. Beds were fumigated with a mixture of 67% methyl bromide and 33% chloropicrin 3 weeks prior to transplanting. An application of 2N-15P-6K fertilizer was broadcast preplant prior to fumigation at 1,347 kg/ha and incorporated into the bed. Additional 16N-24K fertilizer at a rate of 1,628 kg/ha was banded just prior to mulching on the bed surface 25 cm from the plant row. Cultivars and planting dates were as follows: experiment I, cv. Cobia, 5 September 1992; experiment II, cv. Merced, 11 September 1993; and experiment III, cv. Merced, 26 January 1994. Cobia and Merced have similar yield potentials and disease susceptibilities. Individual plots consisted of three rows 15.2 m long, spaced 1.8 m apart, with 0.3 m between plants in a row.

Treatments were fungicides applied once or twice a week with a tractor-mounted, hydraulic-boom sprayer at a pressure of 1.4×10^7 dynes/cm^2. Spray nozzles were equipped with no. 25 cores with D-3 orifices (Spraying Systems, Inc., Wheaton, IL). Spray volume was adjusted for plant growth by the addition of nozzles to the boom until a volume of approximately 1,200 liters/ha was made to mature plants. In experiment I, the five treatments were chlorothalonil (Bravo 720, ISK Biosciences Corp., Marietta, GA), 2.5 kg a.i./ha applied once or twice per week; a tank mix of mancozeb (Manzate 200 DF, E.I. Dupont Nemours & Co., Wilmington, DE), 1.35 kg a.i./ha and copper hydroxide (Kocide 101, Griffin Corp., Valdosta, GA), 1.2 kg metallic Cu/ha applied once or twice a week; and the unsprayed control. Sprays were initiated 22 September and terminated 4 December. In experiments II and III, a combination product of chlorothalonil, 1.5 kg a.i./ha, maneb 0.3 kg a.i./ha, and copper oxychloride, 1.5 kg metallic Cu/ha (Bravo C/M), was substituted for the chlorothalonil twice-a-week regimen. Sprays for experiment II were

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Table 1. Value of tomato crop harvested from experimental plots, cost of control, and net returns for fall 1992 field trial (experiment I), Immokalee, FL

Treatment[a]	Yield of extra-large fruit (kg)[b]	Value of extra-large fruit ($)	Total marketable yield (kg)	Total value of crop ($)	Cost of fungicides ($)	Estimated application costs ($)	Total costs ($)	Net return ($)[c]
Chlorothalonil 2x/wk	20,000	19,355	41,241	31,352	862	96	958	30,393
Chlorothalonil 1x/wk	19,567	18,631	40,793	30,793	474	52	526	30,267
Copper-mancozeb 2x/wk	16,833	16,028	39,224	28,896	375	96	472	28,425
Copper-mancozeb 1x/wk	15,331	14,598	32,052	24,154	207	52	259	23,895
Control	15,017	14,299	29,362	22,556	...	...	0	22,556

[a] Chlorothalonil (Bravo 720, 2.5 kg a.i./ha); copper (Kocide 101, 1.2 kg Cu/ha); mancozeb (Manzate 200 DF, 1.35 kg a.i./ha). Number of applications were: 1x/wk = 11 and 2x/wk = 22.
[b] All data reported on a per hectare basis.
[c] Grower can realize a net return increase of up to ($30,393 – $22,556) = $7,837/ha from using fungicides. For a 324-ha farm, net return = $2,539,188.

Table 2. Preplanned single-degree-of-freedom orthogonal contrasts, orthogonal contrast sum of squares (CSS), and *F* test values for yield components in experiment I (fall 1992) at Immokalee, FL

	Total harvest		Marketable fruit		Extra-large fruit		Fruit damage from target spot (%)	
Preplanned contrasts	CSS	*F* test	CSS	*F* test	CSS	*F* test	CSS	*F* test
Control vs. treated	115.88	10.34**[a]	534.72	27.18**	150.06	14.89**	0.19	32.14**
Chlorothalonil vs. Cu + mancozeb	97.55	8.70**	566.47	28.79**	127.51	12.66**	0.19	32.82**
Chlorothalonil 1x/wk vs. chlorothalonil 2x/wk	8.56	0.76	2.68	0.14	1.46	0.14	0.00	0.15
Cu + mancozeb 1x/wk vs. Cu + mancozeb 2x/wk	0.11	0.01	2.02	0.10	9.41	0.93	0.01	1.90

[a] ** Denotes significant difference(s) at $P = 0.01$.

Table 3. Value of tomato crop harvested from experimental plots, cost of control, and net returns for fall 1993 field trial (experiment II), Immokalee, FL

Treatment[a]	Yield of extra-large fruit (kg)[b]	Value of extra-large fruit ($)	Total marketable yield (kg)	Total value of crop ($)	Cost of fungicides ($)	Estimated application costs ($)	Total costs ($)	Net return ($)[c]
Chlorothalonil + Cu/mancozeb 1x/wk	20,172	14,227	43,259	26,439	543	52	595	25,844
Chlorothalonil 1x/wk	22,862	16,124	52,000	33,221	529	52	581	32,641
Copper-mancozeb 2x/wk	17,034	12,014	35,638	22,625	457	52	561	22,065
Copper-mancozeb 1x/wk	19,724	13,911	40,121	25,550	227	104	279	25,271
Control	10,759	7,589	28,690	17,784	...	...	0	17,784

[a] Chlorothalonil (Bravo 720, 2.5 kg a.i./ha); copper (Kocide 101, 1.2 kg Cu/ha); mancozeb (Manzate 200 DF, 1.35 kg a.i./ha). Number of applications were: 1x/wk = 11 and 2x/wk = 22.
[b] All data reported on a per hectare basis.
[c] Grower can realize a net return increase of up to ($32,641 – $17,784) = $14,857/ha from using fungicides. For a 324-ha farm, net return = $4,813,668.

begun 28 September and terminated 10 December. Applications for experiment III were made from 26 January through 29 April.

Weeds in the row middles were controlled with a preplant application of metribuzin at 0.56 kg a.i./ha, and one or two applications of paraquat dichloride at 0.7 kg a.i./ha as needed during crop growth. Insects were controlled as needed based on field-scouting results (14), primarily with avermectin, *Bacillus thuringiensis*, and methamidophos.

Severity of foliar diseases was rated weekly beginning approximately 1 month after transplanting. No attempt was made to differentiate foliar diseases based on field symptoms. The sampling unit was all the plants in the center row of each plot. An estimate of the percentage of foliage covered by disease and foliage lost due to disease were combined into one rating. The proportion of plants with any visible foliar disease was determined based on a count of the number of plants in a plot. This proportion was multiplied by another representing an estimate of the average amount of foliar damage per infected plant in order to arrive at a final proportion of diseased plant material per plot.

Plots were harvested twice in each experiment. The first harvest occurred at the mature-green stage (i.e., when about 5% of the fruit were beginning to show pink coloration) and again approximately 16 days later. All fruit considered to be of sufficient size and maturity to make USDA standards were picked from 1.8 m of the interior row of each plot. Culls were sorted and assigned to one of several defect categories. Sizes of marketable fruit were determined by passing them through hand-held templates with circular openings corresponding to size grades (Florida Tomato Committee, Orlando). Data from the two harvests were combined for analysis.

Statistical analyses were performed using the Statistical Analysis System (Cary, NC). Standard iterative procedures were used to calculate areas under the disease progress curve (16). All data were subjected to ANOVA, followed by a series of preplanned single-degree-of-freedom orthogonal contrasts as suggested by Swallow (19) using the procedures outlined by Steel and Torrie (18). In some cases, percentage data were converted to their arcsine-square root equivalents in order to normalize data sets prior to analysis (18).

RESULTS

In two of the three tests, the benefits accruing to Florida growers from the use of fungicides were clearly demonstrated. In experiment I, total marketable yields were reduced over 30% when no fungicides were used, as compared to the highest yielding treatment (chlorothalonil, twice a week) (Table 1). This same trend was also recorded for the extra-large fruit, the grade bringing the highest return to the producer. Treatment with chlorothalonil resulted in a

Table 4. Preplanned single-degree-of-freedom orthogonal contrasts, orthogonal contrast sum of squares (CSS), and *F* test values from yield components in experiment II (fall 1993) at Immokalee, FL

	Marketable fruit		Extra-large fruit		Fruit damage from target spot (%)	
Preplanned contrasts	**CSS**	***F* test**	**CSS**	***F* test**	**CSS**	***F* test**
Control vs. treated	146.63	15.96**[a]	65.76	23.33**	0.06	10.04**
Chlorothalonil vs. Cu/mancozeb	99.41	10.82**	10.10	3.58	0.09	15.02**
Chlorothalonil vs. chlorothalonil + Cu/mancozeb	42.02	4.57*	3.71	1.32	0.08	13.78**
Cu + mancozeb 1x/wk vs. Cu + mancozeb 2x/wk	9.82	1.07	3.48	1.24	0.00	0.95

[a] * Denotes significant difference(s) at $P = 0.05$ and ** denotes significant difference at $P = 0.01$.

Table 5. Value of tomato crop harvested from experimental plots, cost of control, and net returns for spring 1994 field trial, Immokalee, FL

Treatment[a]	Yield of extra-large fruit (kg)[b]	Value of extra-large fruit ($)	Total marketable yield (kg)	Total value of crop ($)	Cost of fungicides ($)	Estimated application costs ($)	Total costs ($)	Net return ($)[c]
Chlorothalonil 1x/wk	46,172	22,388	67,690	29,383	529	52	581	28,803
Chlorothalonil + Cu/mancozeb 1x/wk	48,190	23,366	71,276	30,875	543	52	595	30,280
Copper/mancozeb 2x/wk	59,621	28,909	90,552	38,947	457	104	561	38,386
Copper/mancozeb 1x/wk	49,759	24,127	75,759	32,525	227	52	279	32,246
Control	46,172	22,388	72,621	30,826	...	...	0	30,826

[a] Chlorothalonil (Bravo 720, 2.5 kg a.i./ha); chlorothalonil + Cu/mancozeb (Bravo C/M, 1.5 kg a.i./ha chlorothalonil, 0.3 kg a.i./ha maneb, and 1.5 kg cu/ha); copper (Kocide 101, 1.2 kg a.i. Cu/ha); mancozeb (Manzate 200 DF, 1.35 kg a.i./ha). Number of applications were 1x/wk = 11 and 2x/wk = 22.
[b] All data reported on a per hectare basis. No significant differences found.
[c] Copper/mancozeb 2x/wk shows a return on investment (compared to control) of ($38,386 – 30,826) = $7,560/ha. For a 324-ha farm, net return on investment = $2,449,440.

crop value in excess of $30,000/ha, based on returns for fresh-market tomatoes in December 1992. In contrast, the unsprayed control plots were valued at $22,500/ha. When accounts were made for fungicide and application costs, net returns were over $7,800/ha higher in the chlorothalonil-treated plots. This translates to profits of $2.5 million for a typical farm (ca. 324 ha) in southwest Florida.

Most of the losses in experiment I were attributable to a late-season epidemic of target spot. In excess of 33% of the fruit had to be culled in control plots due to the presence of target spot blemishes. In contrast, only 4 to 5% of the fruit were culled because of target spot in the chlorothalonil-treated plots (data not shown). Total, marketable, and extra-large fruit yields were all significantly higher when chlorothalonil rather than copper-mancozeb was sprayed (Table 2). The superior performance of chlorothalonil in these plots was a direct result of the reduced fruit damage caused by the target spot fungus, based on *F* test values for preplanned contrasts comparing percentage of target spot culls. The increased cost of chlorothalonil over copper-mancozeb was more than offset by the increased value of the marketable crop.

Similar results were recorded in experiment II (fall 1993). Total marketable yield was reduced 43% when no fungicide was used compared to the best treatment (chlorothalonil once a week) (Table 3). Investment in chlorothalonil resulted in a return at harvest of more than $14,000/ha compared to unsprayed control plots, based on tomato prices in Florida in December

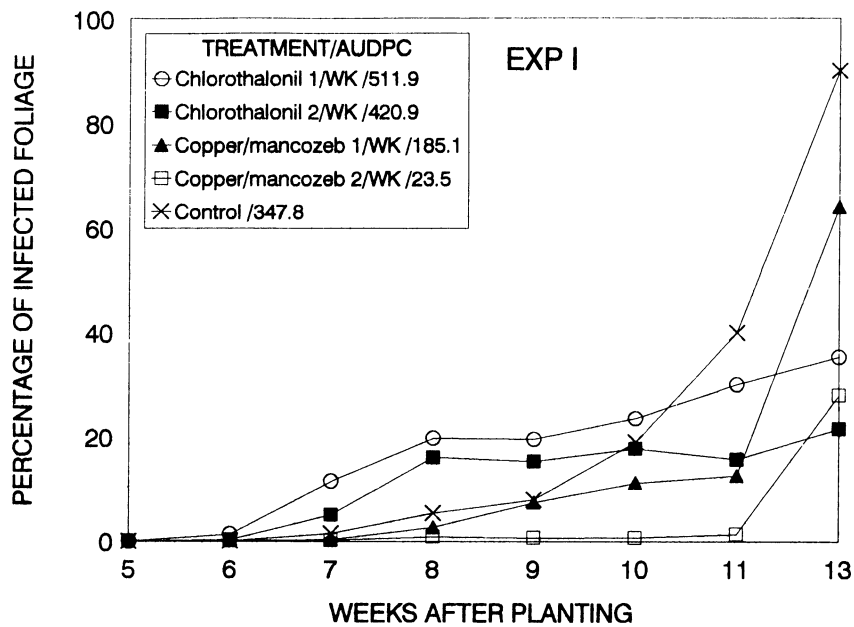

Fig. 1. Development of foliar diseases and areas under the disease progress curve (AUDPC) for fresh-market tomatoes (cv. Cobia) in fall 1992 (experiment I).

1993. Most of the yield losses again were associated with the late-season appearance of target spot. Nearly two-thirds of the fruit had to be culled with target spot lesions in control plots. As in experiment I, marketable and large-fruit yields in chlorothalonil-treated plots were higher than in those receiving spays of copper-mancozeb (Table 4), and led to higher net returns (Table 3).

The benefits gained from protectant fungicides were less clear in the spring 1994 test (experiment III). Target spot was not a major factor in defoliation or direct fruit injury. Bacterial spot was present throughout the crop. No significant increases in marketable yield were recorded (Table 5). *F* tests for treatments in the ANOVA and in the single-degree-of-freedom orthogonal contrasts were not significant at $P = 0.05$. As a whole, little return on investment in protectant fungicides could be shown in this particular trial.

Target spot and bacterial spot were often involved in defoliation in the same experiment. However, target spot levels usually increased dramatically as the first harvest approached. Much of the loss associated with target spot was the result of direct damage to the fruit by the fungus, based on the distinctive fruit symptoms seen at harvest. Since much of the defoliation early in crop development was due to bacterial spot, disease-progress curves did not necessarily correspond to marketable yield losses. For example, in both experiments I and II, disease ratings were relatively high in plots treated once a week with chlorothalonil (Figs. 1 and 2), but marketable yields were among the highest recorded (Tables 1 and 2). The AUDPC values for the chlorothalonil plots were approximately four times higher in experiment I than the values for the copper-mancozeb plots. These differences were significant ($P = 0.01$) based on the appropriate single-degree-of-freedom orthogonal contrasts (data not shown). However, the late-season defoliation, and especially the severe fruit infection associated with target spot, were primarily responsible for the observed losses.

In experiment III, target spot was not a major factor in either defoliation or direct fruit injury. Bacterial spot was present throughout the crop (Fig. 3). However, F tests for total, marketable, or extra-large fruit yields were not significant among treatments ($P = 0.05$).

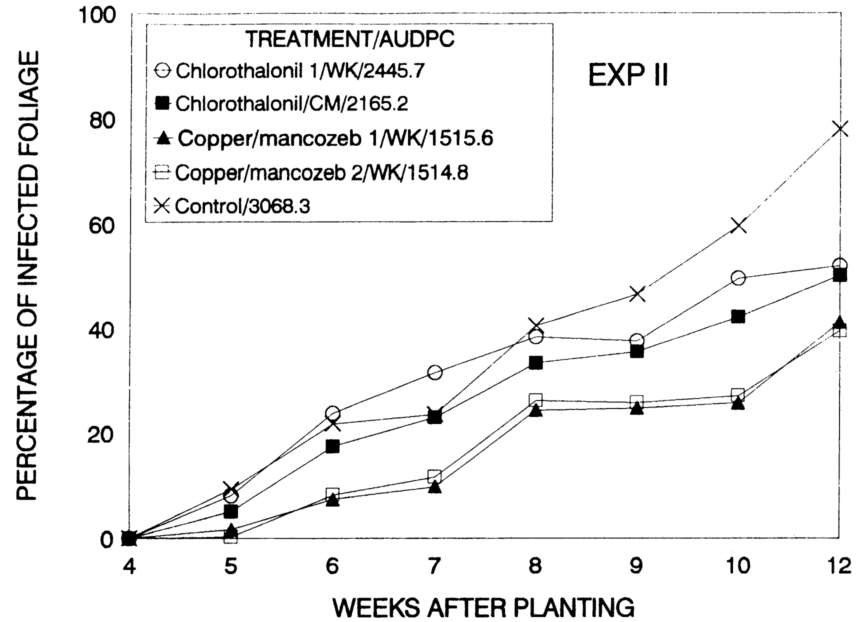

Fig. 2. Development of foliar diseases and area under the disease progress curve (AUDPC) for fresh-market tomatoes (cv. Merced) in fall 1993 (experiment II).

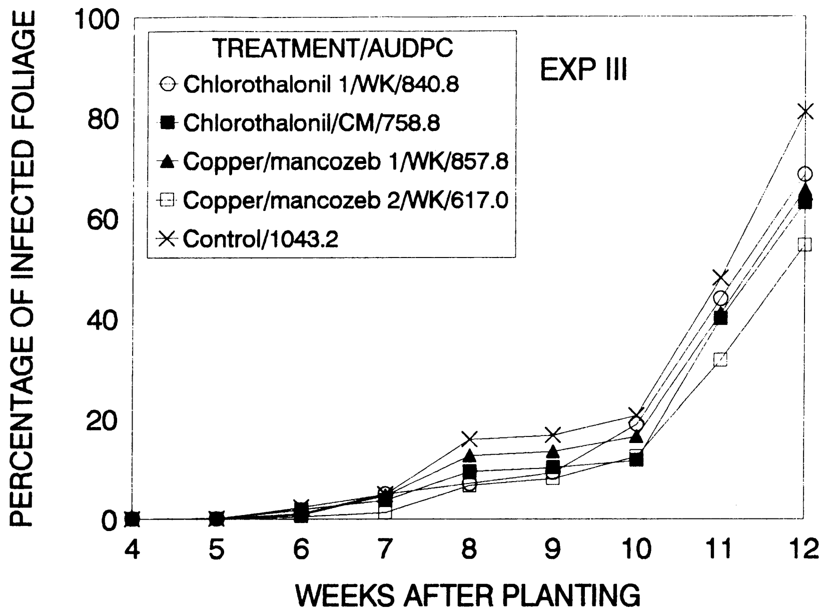

Fig. 3. Development of foliar disease and area under the disease progress curve (AUDPC) for fresh-market tomatoes (cv. Merced) in spring 1994 (experiment III).

DISCUSSION

In two of these three experiments, we present clear evidence, gathered under commercial growing conditions, that fungicide sprays contribute substantially to the productivity and economic viability of the Florida tomato industry. These are the types of data needed by professional staff at the EPA who must make cost-benefit decisions, especially relative to the re-registration of widely used pesticides. We are suggesting a specific protocol for evaluation of economic impacts for fresh-market tomatoes, especially in the Southeast. Bulking of yields, which can be done for processing tomatoes, will result in underestimation of losses for fresh-market conditions. The major effect of tomato foliar pathogens seems to be in the reduction in the yield of extra-large fruit (13), the tomatoes bringing the highest returns to growers. Although much more work must be done by researchers to separate harvested fruit into standardized size categories, the data required by regulatory agencies almost certainly dictate such an experimental protocol. The data reported here may serve as a basis for agriculturally favorable decisions in current and future litigation and decision-making (6,10).

Bacterial spot, often considered the number one foliar disease of tomato in Florida (3,8,14,17), was present in each of the three tests. However, there was little correlation between levels of bacterial spot and subsequent yield variables measured at harvest. Large yield losses due to bacterial spot were recorded when epidemics were initiated early in crop development (13). It may be that the natural levels of spot occurring in these tests were below damage thresholds at some critical period early in the growth of the plants. In addition, few fruit were discarded because of bacterial spot blemishes. Inoculum must be available when fruit are quite small for incidence of fruit infection to be high (15). Sandblasting also can be important in bacterial spot damage to fruit (12). These conditions may not have been met during our trials.

Most of the yield loss that was recorded was attributable to direct damage by *C. cassiicola* to the tomato fruit. Previous reports also emphasized the importance of fruit damage by this pathogen (1,20). Losses from target spot were less than those recorded in controlled studies for bacterial spot (13) and Septoria leaf spot (4). The approximately 30% loss was similar, however, to that recorded for black leaf mold (7). It would seem prudent to change recommendations for tomato disease control to reflect the importance of target spot damage late in the crop development, especially with fall-planted tomatoes.

In some cases (as in experiment III), returns may not justify input costs for fungicides. However, at present, we do not have disease forecasting systems with the degree of reliability necessary to determine when risks are minimal and protectant-fungicide applications may be reduced or eliminated. Past attempts to apply prediction systems from other parts of the country to southern Florida have met with little success (14). What's more, growers must deal with an even more difficult task when attempting to predict market prices at harvest. Until biological and economic research provide needed answers, growers are best advised to minimize risks by judicious use of protectant fungicides.

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