Fungicide Timing for Optimum Management of Gummy Stem Blight Epidemics on Watermelon

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ABSTRACT

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During the fall of 1991 and 1993, four fungicide-application intervals were evaluated on watermelon for control of gummy stem blight, caused by *Didymella bryoniae*. Chlorothalonil combined with benomyl was applied full season (six times), early season (first half of the season, three or four times), late season (last half, two or three times), or not applied. During both years, early- and full-season applications reduced areas under disease progress curves compared with no-fungicide, and late-season applications gave less control than full-season applications ($P \leq 0.01$). Slopes of disease progress curves changed over time in relation to fungicide applications and amount of healthy tissue remaining. In 1993, yields of marketable fruit were lower in all plots that received three or no sprays than in plots that received six sprays. In two additional experiments, areas under disease progress curves were lowest for chlorothalonil plus benomyl during both the fall of 1991 and the spring of 1993 compared with weekly applications of chlorothalonil alone, mancozeb, or alternating chlorothalonil with mancozeb. A minimum of six fungicide applications are required to manage gummy stem blight adequately on watermelon grown in disease-conducive environments.

Additional keywords: *Citrullus lanatus, Phoma cucurbitacearum*

Didymella bryoniae (Auersw.) Rehm (=*Mycosphaerella citrullina* (C.O. Sm.) Gross.), anamorph *Phoma cucurbitacearum* (Fr.:Fr.) Sacc. (=*Ascochyta cucumis* Fautrey & Roum.), causes gummy stem blight of cucurbits (species of *Citrullus, Cucumis, Cucurbita,* and other genera). In the southeastern United States, gummy stem blight is the most destructive foliar disease of watermelon (*Citrullus lanatus* (Thunb.) Matsum. & Nakai) (A. P. Keinath, *personal observation*) and cucumber (16). As multiple resistances to other foliar diseases, e.g., downy mildew and anthracnose, have been incorporated into cucumbers and other cucurbits, losses due to gummy stem blight have increased (15,18). No available cucurbit cultivars have commercially acceptable levels of resistance to this pathogen (12,18,24). Gummy stem blight was especially severe on watermelon in South Carolina and other southeastern states in 1991, when over 15% of the watermelon acreage in South Carolina was abandoned before harvest (13).

Gummy stem blight often is inadequately controlled by fungicides currently registered for use on cucurbits (benomyl, chlorothalonil, mancozeb, maneb, and thiophanate-methyl) (2,7, 12,19). Poor fungicide performance may be due to rapid infection of foliage by *D. bryoniae* (1,22), inadequate coverage of leaves within cucurbit canopies by fungicides (25), poor retention of fungicides on cucurbit leaves when precipitation is heavy (17), or resistance to benzimidizoles in pathogen populations (11,23). Increased public concern about the safety of pesticides and undesirable effects of pesticides on nontarget organisms necessitates development of effective, economical, and environmentally sound disease-control strategies to ensure continued profitable vegetable production in the humid eastern United States.

The objective of this study was to evaluate the need for season-long fungicide applications to manage the foliar phase of gummy stem blight on cucurbits. An initial hypothesis was that fungicide applications must be initiated at the time of first fruit set to prevent yield loss. The most effective fungicide treatment was determined by evaluating materials in different classes of fungicides (aromatics, ethylenebisdithiocarbamates, and benzimidazoles) currently registered for gummy stem blight control on watermelon. A preliminary report has been presented (6).

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MATERIALS AND METHODS

Cultural practices for fungicide intervals. Field plots were established at the Clemson University Coastal Research and Education Center (CREC), Charleston, SC, in Nosbig fine sandy loam that had been cropped to winter wheat (*Triticum aestivum*) and rye (*Secale cereale*) prior to the 1991 and 1993 experiments, respectively. In 1991, 1,3-dichloropropene plus 17% chloropicrin (Telone C-17, 61 L/ha) was injected into the soil for nematode control, and N at 90 kg/ha and K at 224 kg/ha (10-0-30 N-P-K fertilizer at 900 kg/ha) were incorporated. In 1993, N at 90 kg/ha, P at 40 kg/ha, and K at 75 kg/ha (10-10-10 N-P-K fertilizer at 900 kg/ha) were applied, and a fumigant was not used. The herbicides ethalfluralin (Curbit 3EC, 1.91 kg/ha) and naptalam (Alanap 2EC, 4.48 kg/ha) were applied pre- and postemergence, respectively, in both years. Watermelon cv. Mirage was direct-seeded (three seeds per hill) on 22 July 1991 and 14 July 1993. Rows were spaced 1.8 m apart with 1.2 m between hills within rows. Plants were sidedressed with N at 34 kg/ha, P at 15 kg/ha, and K at 28 kg/ha in 1991 and N at 45 kg/ha, P at 20 kg/ha, and K at 37 kg/ha in 1993 (10-10-10 N-P-K fertilizer) when the vines began to run. The insecticides esfenvalerate (Asana, 0.056 kg/ha) and endosulfan (Thiodan, 1.1 kg/ha) were applied once in 1991, and esfenvalerate was applied twice in 1993 to control striped and spotted cucumber beetles.

Fungicide-interval treatments. The experiment was a randomized complete block with three and four replications in 1991 and 1993, respectively. Experimental plots were 15.2 m long and four and three rows wide in 1991 and 1993, respectively. Each plot was separated by 3 m of unsprayed vines within rows and by one unplanted row on either side. The length of the season during which a protectant and a systemic fungicide were applied was varied by delaying or halting fungicide applications compared with full-season applications. Application intervals were selected based on plant growth stages that could be recognized easily by growers. A mixture of chlorothalonil (Bravo 720, 1.73 kg/ha) and benomyl (Benlate 50WP, 0.28 kg/ha) was applied to treated plots at weekly intervals. The treatment intervals were: 1) full season (six applications beginning at vine run [25 and 28 days after planting in 1991 and 1993, respectively]); 2) early season (first half of the season, four and three applications from vine run to fruit set [52 and 47 days after planting] in 1991 and 1993, respectively); 3) late season (last half, three [1991] and two [1993] applications beginning at fruit set); and 4) no fungicides applied. In 1991, fungicides were applied in 230 L of water per hectare at 207 kPa with a hydraulic boom sprayer with five Teejet cone nozzles (disc D3, core #25, Spraying Systems Co., Jacksonville, FL) spaced 30.5 cm apart. In 1993, fungicides were applied in 270 L of water per hectare with a CO_2-pressurized backpack sprayer with a constant boom pressure of 276 kPa and four Teejet fan nozzles (#003) spaced 45.7 cm apart.

Vines in the center 12.3 m of each row of each plot were rated visually with the Horsfall-Barratt scale (3) six times in 1991 and seven times in 1993. 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. Disease severities were used to calculate areas under the disease progress curve (AUDPC). On 30 September 1993, melons were harvested from the center row of each plot, weighed, and graded according to the U.S. Department of Agriculture standards. Melons >6.35 kg in grades 1 and 2 were considered marketable. Melons left in the field did not reach marketable size. The average price for melons harvested in 1993 in South Carolina was $0.11/kg (Southeastern Melon, Islandton, SC). Economic returns were calculated as return/hectare = (weight of marketable melons [kilograms per hectare] × $0.11 per kilogram) − (cost of fungicide materials per hectare × number of applications).

Cultural practices for fungicide comparisons. Field plots were established at CREC in Nosbig fine sandy loam in 1991, previously cropped to winter wheat, and in Bayboro sandy clay loam in 1993, previously cropped to collard (*Brassica oleracea* var. *acephala*). Fields were prepared by injecting 1,3-dichloropropene plus 17% chloropicrin (Telone C-17, 61 L/ha in 1991 and 28 L/ha in 1993) and incorporating N at 90 kg/ha and K at 224 kg/ha (10-0-30 N-P-K fertilizer at 900 kg/ha) in 1991 and N at 84 kg/ha and K at 70 kg/ha (15-0-15 N-P-K fertilizer at 560 kg/ha) in 1993. In 1991 herbicides were applied as described previously. In 1993 the herbicides bensulide (Prefar 4E, 6.73 kg/ha) and naptalam (3.36 kg/ha) were applied preplant. Watermelon cvs. Charleston Gray and Mirage were direct-seeded (three seeds per hill) on 22 July 1991; cvs. Charleston Gray and Jubilee II were direct-seeded on 19 April 1993. Rows were spaced 1.8 m apart, with 1.2 m between hills within rows. Plants were sidedressed as described previously. Insecticides were applied as described previously, except esfenvalerate was applied once in 1993.

Fungicide treatments. The experimental design was a split plot, with cultivar as the whole-plot treatment and fungicide as the subplot treatment. There were two replications of each cultivar and four replications of each fungicide. Subplots were 15.2 m long, three and two rows wide in 1991 and 1993, respectively. In 1991, one row was left unsprayed between subplots, and 3.1 m of vines was left unsprayed within rows at the ends of subplots. In 1993, subplots were separated by one unplanted row and 6.2 m of unsprayed vines within rows. Natural inoculum was present in the plots in 1991. On 9 June 1993, two plants on opposite ends of one row in each plot were sprayed to runoff with 1.9×10^5 cfu of *D. bryoniae* isolate APK-W4 per milliliter. *D. bryoniae* was grown on quarter-strength potato-dextrose agar (QPDA) for 3 wk under a 12-h photoperiod at ambient temperature (22–26 C). Conidia and mycelia from 38 petri plates were suspended in 4 L of sterile distilled water. Colony-forming units were determined by dilution-plating the inoculum suspension on QPDA. In 1993, plots were irrigated during mornings, 2–3 days/wk,

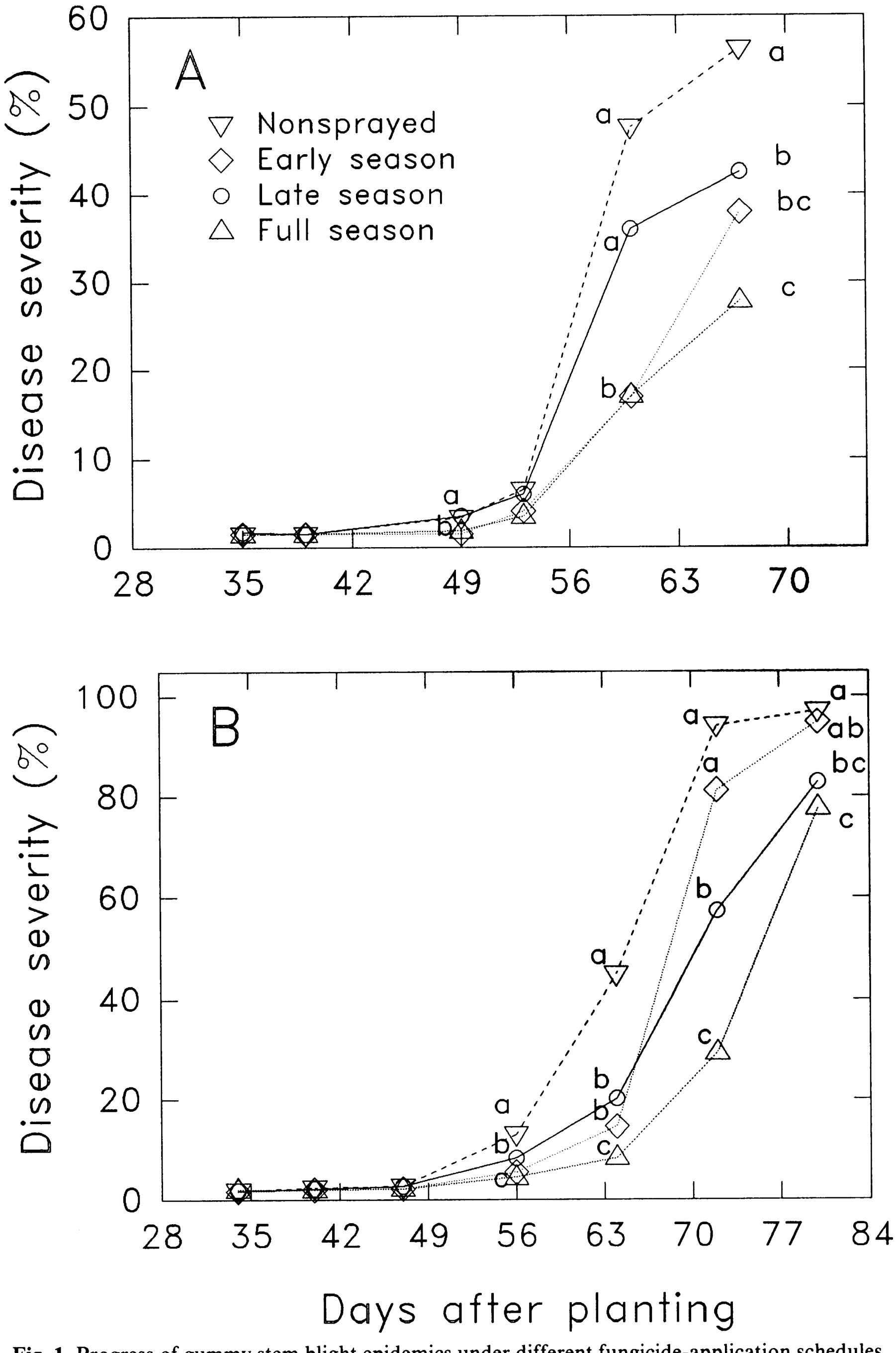

Fig. 1. Progress of gummy stem blight epidemics under different fungicide-application schedules on watermelon cv. Mirage in field plots in **(A)** 1991 and **(B)** 1993. Repeated measures analysis of variance showed a significant time × treatment interaction ($P = 0.0045$ and 0.0001 in 1991 and 1993, respectively). Mean disease severities (percent leaf surface area diseased) with the same letter at each rating time are not significantly different (Waller-Duncan *k*-ratio *t* test; $k = 100$; $P = 0.05$).

so that the combined total of rainfall and irrigation averaged 3–4 cm/wk.

Fungicides were applied on a 7-day schedule between 22 August and 25 September 1991 and 16 June and 22 July 1993, a total of six sprays each year. Four fungicide combinations, chlorothalonil (Bravo 720, 1.73 kg/ha) and mancozeb (Manzate 200DF, 1.68 kg/ha) applied alone and alternated on a 14-day schedule and chlorothalonil plus benomyl (Benlate 50WP, 0.28 kg/ha), were tested with a no-fungicide control. In 1991 application rates remained constant for the entire season (7), whereas in 1993, rates for chlorothalonil and mancozeb were increased on the third week by 50% (2) to the maximum rates registered for gummy stem blight control. Fungicides were applied with the sprayers described previously. Vines in all rows of all plots were rated with the Horsfall-Barratt scale (3) three times each year (12 and 24 September and 10 October 1991 and 10, 19, and 28 July 1993). Disease severities and AUDPCs were calculated as described previously. On 28 July 1993, all marketable melons (grades 1 and 2) were harvested from the center 7.6 m of the inoculated row in each plot for both cultivars. The harvested section did not include the inoculated plants. No yield data were taken in 1991 because fruit set was poor and many melons rotted in the field before harvest due to above-average rainfall during September, 21.6 cm compared to 12.0 cm (30-yr average).

Data analysis. Analysis of variance and repeated measures analysis of variance were performed with PROC GLM of SAS, version 6.04 (SAS Institute, Inc., Cary, NC). Before analysis, data were tested for homogeneity of variance and normality. The effect of year on repeated experiments was tested with a split-unit analysis, with year as the whole unit and treatments as the subunits. Treatment means were compared with the Waller-Duncan k-ratio t test or Fisher's protected least significant difference test. Repeated measures analysis of variance was used to compare epidemic progress in the fungicide-interval experiments. A full polynomial model (fifth-order in 1991 and sixth-order in 1993) was fit to the data. Probabilities of greater F values were based on degrees of freedom adjusted with the Greenhouse-Geisser epsilon to account for significant serial correlations between disease severities at successive times (10). Plots of disease progress curves for each replication of each treatment were used to determine empirically the day after planting on which disease severity reached 10%. Neither nonlinear models (logistic and Gompertz) nor the logit transformation of disease severity ($\ln[y/1 - y]$) fit the data for all fungicide interval treatments in either year.

RESULTS

Fungicide intervals. Progress of the epidemics generated by different fungicide intervals differed from each other throughout the season during both years (significant time × treatment interaction, $P \leq 0.01$). Early- and full-season treatments had significantly lower disease severities than late-season and unsprayed treatments by 49 days after planting in 1991 and 56 days after planting in 1993 (Fig. 1). For the remainder of the 1991 season, disease severity in the early-season treatment did not differ significantly from that in the full-season treatment. In 1993, disease severity in the early-season treatment was significantly greater than that in the full-season treatment by 64 days after planting.

All fungicide treatments significantly ($P \leq 0.01$) lengthened the time required to reach 10% disease severity by an average of 5–11 days compared with the no-fungicide treatment in 1993 but not in 1991 (Table 1). The slope of the disease progress curve during the middle of the season (53–60 and 56–64 days after planting in 1991 and 1993, respectively) was 0.039 and 0.034 greater in the unsprayed treatment than in the full-season treatment in 1991 and 1993, respectively. During this period, epidemics progressed most rapidly in unsprayed plots, but by 60–67 and 64–72 days after planting in 1991 and 1993, respectively, epidemic progress was most rapid in early-season plots. In both years, early- and full-season applications reduced AUDPC values compared to no fungicide ($P \leq 0.01$). Late-season applications consistently gave less disease control than full-season applications. Early-season fungicide applications reduced AUDPC values as much as full-season applications did in 1991, when four sprays were used, but not in 1993, when three sprays were used.

In 1993, weight of marketable melons (fruits > 6.35 kg) from full-season plots was greater than fruit weights in unsprayed, early-, and late-season plots ($P = 0.05$) (Table 2). Neither reduced spray interval increased total weight, weight of grade 1 melons (data not shown), or weight of marketable melons compared with the no-fungicide control. Total fruit weight was greater in early-season plots than in late-season plots ($P = 0.05$), but weight of marketable fruit did not differ significantly between these two treatments. Average weight of individual fruits in both grades (7.2 ± 2.2 [SD]) did not differ among treatments. Economic returns for full-season plots were significantly greater than returns for early-season plots but not different than returns for plots that received no fungicide (Table 2).

Fungicide comparisons. Final disease severity was ≥55% in all treatments at the end of both seasons (Table 3). The cultivars used in both years were very susceptible to *D. bryoniae* and reacted similarly to the fungicides (cultivar × treatment and cultivar × year interactions not significant, $P > 0.10$). In 1993 there was no treatment × row inoculation interaction, so disease severities for each plot were calculated from inoculated and uninoculated rows. There was no statistically significant effect of any treatment on yield in 1993 (2).

Table 1. Comparison of disease progress curves for gummy stem blight epidemics on watermelon cv. Mirage in fungicide-interval plots during the fall of 1991 and 1993

	Days to 10% disease severity[u]		Slope of disease progress curve segments				AUDPC[v]	
			1991[w]		1993			
Treatment	1991[w]	1993	53–60 dap	60–67 dap	56–64 dap	64–72 dap	1991	1993
No fungicide	54.0	52.7 c[x]	0.0587 a	0.0126 b	0.0391 a	0.0616 b	601.9 a	1,651 a
Early season	56.3	60.0 b	0.0130 c	0.0300 a	0.0127 bc	0.0833 a	292.4 bc	1,226 b
Late season	54.0	57.7 b	0.0428 ab	0.00925 b	0.0147 b	0.0465 bc	486.0 ab	1,061 b
Full season	59.3	64.0 a	0.0193 bc	0.0155 b	0.00484 c	0.0262 c	270.2 c	686 c
MSD[y]	NS[z]	3.2	0.0236	0.0124	0.00815	0.0203	212.43	177.9

[u] Days after planting.
[v] Area under the disease progress curve (AUDPC) calculated from disease severity ratings.
[w] Data were analyzed by year because of an interaction between year and treatment (F significant at $P \leq 0.01$).
[x] Means within a column with the same letter are not significantly different according to the Waller-Duncan k-ratio t test, $k = 500$ ($P = 0.01$) for 10% disease severity and AUDPC and $k = 100$ ($P = 0.05$) for slopes.
[y] Minimum significant difference.
[z] No significant differences.

Fungicide treatments that included mancozeb were not effective in 1991 (Table 3). Chlorothalonil plus benomyl was the most effective treatment, based on the level of gummy stem blight throughout the season. All fungicides reduced gummy stem blight compared with the control in 1993. As in 1991, chlorothalonil plus benomyl was among the most effective treatments. Unlike 1991, alternating chlorothalonil with mancozeb was as effective as weekly applications of chlorothalonil alone. In both years, a mixture of chlorothalonil plus benomyl significantly reduced AUDPC values compared with chlorothalonil applied alone.

DISCUSSION

In general, epidemics of gummy stem blight on watermelons receiving fungicides were delayed in time and progressed more slowly than epidemics on unsprayed plants. Combining a protectant (chlorothalonil) with a systemic (benomyl) fungicide effectively reduced the early and midseason level of inoculum and rate of epidemic development in this polycyclic disease. During both seasons, epidemics of gummy stem blight began to progress rapidly by 50 days after planting, the time of first fruit set. By this stage of crop development, a dense canopy of leaves and vines retards evaporation of moisture on older leaves within the canopy and lengthens leaf wetness periods (14). *D. bryoniae* requires 1 h of leaf wetness to infect cucurbit leaves, and continuous leaf wetness is necessary for lesion expansion (1,22). Reducing the number of fungicide applications resulted in higher disease severity and lower yields than full-season (6 wk) applications. The portion of the season during which reduced fungicide applications were used did not appreciably alter their effectiveness. Plots treated with fungicide during the early or late half of the season had statistically equivalent levels of disease (AUDPC) in both years and similar marketable yields in 1993. Although AUDPC values were lower for the reduced fungicide treatments than for the no-fungicide treatment, the reduction in disease was not great enough to result in higher marketable yields.

In both years, gummy stem blight severity in the early-season treatment remained low for 2 wk after fungicide applications were halted. Thereafter (approximately 65 days after planting), the rate of epidemic progress in this treatment was more rapid than rates for all other treatments, probably because a greater amount of unprotected tissue remained. In 1993, the rate of epidemic progress at the end of the season was so great it completely negated the disease control realized when plots were sprayed during the early portion of the season. The difference in effectiveness of the early-season treatment between 1991 and 1993 appears to be related to the amount of rain that fell during the fungicide-application periods. In 1991, 24.7 cm of rain fell while the foliage was protected in the early-season treatment and 0.9 cm fell during the late-season treatment. In 1993, 3.5 and 14.5 cm of rain fell during the period covered by the early and late treatments, respectively. The early-season treatment kept gummy stem blight severity low when fungicide applications coincided with rainfall.

Disease severity in the late-season treatment, which was initiated at fruit set, had reached 10 and 2% in 1991 and 1993, respectively, when fungicide applications began. This treatment sustained more disease over the entire season than did the full-season treatment in both years, and yields in 1993 were as low as the no-fungicide treatment. Clearly, the amount of infected tissue must be kept low from the beginning of the season to adequately manage gummy stem blight. Similarly, the time period during which Alternaria leaf blight on muskmelon was kept ≤1% was critical for preventing yield loss (9). When a threshold of 10% anthracnose was used to initiate chlorothalonil applications, yield loss on pickling cucumber was significant (20).

Chlorothalonil combined with benomyl was the most effective fungicide treatment to reduce foliar symptoms of gummy stem blight on watermelon. In a field trial on cucumber, chlorothalonil was more effective than benomyl at preventing defoliation and yield loss due to gummy stem blight (4). On European greenhouse cucumber, benomyl was the most effective fungicide, followed by chlorothalonil, for control of gummy stem blight (21). Both materials were more effective when applied weekly than biweekly. Resistance to benomyl in *D. bryoniae* populations in greenhouses has been documented in Greece (11), the Netherlands (22), and Japan (5). Because of the potential for selecting isolates of *D. bryoniae* resistant to benzimidazole, benomyl applied alone was not included in the fungicide efficacy comparisons.

Mancozeb was not effective in 1991 during a season with above-average

Table 2. Yields of watermelon cv. Mirage in fungicide-interval plots in the fall of 1993

Treatment	Total weight of melons (kg/15-m row)[w]	Weight of marketable melons (kg/15-m row)[x]	Economic return ($/ha)[y]
No fungicide	27.3 bc[z]	16.5 b	649.40 ab
Early season	33.8 ab	12.1 b	331.62 b
Late season	18.6 c	12.9 b	365.14 ab
Full season	43.0 a	26.6 a	756.57 a

[w] Melons were harvested from the middle of three rows in each plot 80 days after planting (30 September 1993). Data are based on three replications because of significant damage to fruit by wildlife in the fourth block.
[x] USDA grade 1 and 2 melons >6.35 kg.
[y] Economic returns were calculated with the formula: return/ha = (weight of marketable melons/ha × \$0.11/kg) − (cost of fungicide materials/ha × number of applications). Example: (12.1 kg/50-ft row) (7,260 row-ft/1 A) (1 A/0.405 ha) (\$0.11/kg) − (\$48.52/ha × 3 applications) = \$331.62/ha.
[z] Means within a column with the same letter are not significantly different according to Fisher's protected least significant difference test, $P = 0.05$.

Table 3. Final disease severities and areas under disease progress curves for watermelons treated with different fungicides in the fall of 1991 and the spring of 1993[t]

Treatment[u]	1991[v]		1993	
	Final disease severity[w]	AUDPC[x]	Final disease severity[w]	AUDPC[x]
No fungicide	94.5 a[y]	1,453 a	85.2 a	715 a
Chlorothalonil or mancozeb[z]	89.9 a	1,473 a	55.4 b	370 bc
Mancozeb	88.5 a	1,671 a	64.0 b	384 bc
Chlorothalonil	67.1 b	971 b	68.3 b	521 ab
Chlorothalonil + benomyl	55.9 c	676 c	56.3 b	322 c

[t] Values represent the mean of two cultivars and two replicates.
[u] Chlorothalonil was applied at 1.73 kg/ha, mancozeb at 1.68 kg/ha, and benomyl at 0.28 kg/ha.
[v] Treatment × year interactions were significant ($P < 0.01$) for both final disease severity and AUDPC. Within each year, treatment × cultivar interaction was not significant ($P > 0.10$).
[w] Final disease severity (percent leaf surface area affected with gummy stem blight) was rated 80 and 70 days after planting in 1991 and 1993, respectively. Data were transformed to arcsine square roots before analysis.
[x] Areas under disease progress curves (AUDPC) were transformed to square roots before analysis.
[y] Means within a column with the same letter are not significantly different (Waller-Duncan k-ratio t test; $k = 100$; $P = 0.05$).
[z] Chlorothalonil and mancozeb were applied every 14 days on an alternating schedule.

rainfall (54.3 cm), but it performed as well as chlorothalonil in 1993, a season with below-average rainfall (23.6 cm + ≥12 cm of irrigation). Mancozeb also was less effective than chlorothalonil in controlling Alternaria leaf blight of cantaloupe (8). Mancozeb residues on cantaloupe leaves held in a wet regime (4 cm of precipitation per 12-h wetting cycle) were significantly lower than chlorothalonil residues (17). Residues of the two fungicides did not differ when plants were held in a dry environment after fungicide application.

In the near future, it may become necessary to justify repeated fungicide applications recommended for disease control by demonstrating a concomitant yield increase. Based on the data presented here, and information from previous studies, chlorothalonil plus benomyl is likely to be the optimum fungicide combination to reduce gummy stem blight on watermelon. At least six applications are necessary under heavy disease pressure to prevent loss of marketable fruit. A reduction in the number of fungicide applications by one-third or one-half did not provide consistent disease protection or prevent yield and economic losses. However, it may be possible to alternate chlorothalonil with benomyl early in the season, begin benomyl applications only after disease is detected, or reduce the rate of benomyl to 0.14 kg/ha to reduce the total amount of pesticide applied per season. Beginning with the 1994 growing season, two manufacturers of chlorothalonil discouraged applications within 21 days of harvest under hot, sunny conditions to prevent phytotoxicity to fruit. They also do not permit chlorothalonil to be tank-mixed with any other product. Given these restrictions, alternating chlorothalonil with benomyl may be the most practical application method.

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