Foliar Disease in Fresh-Market Tomato Grown in Differing Bed Strategies and Fungicide Spray Programs

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ABSTRACT

Mills, D. J., Coffman, C. B., Teasdale, J. R., Everts, K. L., Abdul-Baki, A. A., Lydon, J., and Anderson, J. D. 2002. Foliar disease in fresh-market tomato grown in differing bed strategies and fungicide spray programs. *Plant Dis.* 86:955-959.

A 3-year field study in central Maryland evaluated foliar disease in fresh-market tomato grown using combinations of four bed strategies and three fungicide programs. Bed strategies included uncovered beds with or without a composted dairy manure amendment or beds covered with black polyethylene or hairy vetch mulch. Fungicide programs included no fungicide, weekly fungicide, or fungicide applications scheduled according to the TOMCAST disease predictor. In plots with hairy vetch-covered beds, early blight caused by *Alternaria solani*, Septoria leaf spot caused by *Septoria lycopersici*, and defoliation were lower versus uncovered beds each year. Early blight and defoliation were lower in beds covered with vetch versus polyethylene mulch in 2 of 3 years. Disease severity, defoliation, and marketable yield were similar for the weekly and TOMCAST fungicide programs, with 40 to 50% fewer sprays using TOMCAST. Marketable yield was similar among bed strategies except for higher yields in covered versus uncovered and unamended beds in a relatively wet year and lower yields in vetch versus polyethylene beds in a dry year.

Additional keywords: black polyethylene, compost, cover crop, hairy vetch, mulch, sustainable agriculture

An increasingly health-conscious society has increased the demand for fresh market vegetables (29). This increasing demand has been satisfied largely through production methods that rely on off-farm inputs, such as polyethylene mulch, petroleum-based fertilizer, and synthetic pesticides. Two unforeseen consequences of the reliance on off-farm inputs have been increased production costs and the unintentional introduction of agrochemicals into nonfarm environments (17). The development of profitable production systems that are less reliant on off-farm inputs offers one approach to mitigate these unintended economic and environmental costs.

Managing foliar disease is necessary for the profitable production of fresh-market tomatoes in the mid-Atlantic region. Calendar-based fungicide application is

commonly used (25), although integrated pest management programs are becoming more common in the Southeast (4). Calendar-based programs typically consist of fungicide application at 7- to 10-day intervals, which begin soon after transplanting and continue through harvest (25). Although this approach is effective, unnecessary fungicide applications occur when weather conditions discourage disease development.

The disease-forecasting model FAST was developed to identify periods favorable for early blight, caused by *Alternaria solani* Sorauer. Compared with a weekly spray program schedule, FAST can schedule fewer sprays (13,19). A disease forecasting model derived from FAST, TOMCAST, identifies conditions favorable for the development of early blight, Septoria leaf spot caused by *Septoria lycopersici* Speg., and anthracnose fruit rot caused by *Colletotrichum coccodes* (Wallr.) S. J. Hughes (21,22). Compared with calendar-based spray programs, TOMCAST use can result in fewer sprays (8,12,25).

The current reliance on calendar-based spraying potentially could be reduced through the use of cultural methods that reduce disease intensity. Cover crops can form an effective organic mulch for

vegetable production (1,3,6). Benefits derived from cover cropping include improved soil conservation (7) and soil properties (15), weed suppression (6,27), and insect pest suppression (20). A sudan grass-based cover crop (*Sorghum bicolor* var. *sudanensis* cv. Trudan 8) was shown to reduce the splash dispersal of conidia of *C. acutatum* Simmonds, the causal agent of strawberry anthracnose (18). Compared with uncovered beds or beds covered with black polyethylene mulch, equivalent or superior tomato yields were achieved in beds mulched with a hairy vetch cover crop (1,3). Tomato production in a hairy vetch system was shown to increase profitability and reduce off-farm chemical inputs compared with black polyethylene mulch or uncovered soil-based systems (10). The greater profitability observed in a hairy vetch system was due to equivalent or greater marketable yield (3), reduced tillage, and reduced need for commercial N input (2).

The amendment of soil with composted organic matter is another cultural practice that potentially could reduce disease intensity. Compared with soil amended with mineral fertilizers or manure, yields were greater using compost amendments (11,14). Tomato yields comparable to those obtained using commercial N resulted from the inclusion of compost into an integrated crop management framework (26). In some systems, disease intensity responded to soil amendment with various types of compost (9,24). Radish and cucumber seedlings grown in potting mixes amended with composted animal manures exhibited lower levels of damping-off disease caused by *Pythium* or *Rhizoctonia* spp. (23). The number of *Rhizoctonia solani*-induced lesions on the hypocotyls of field-grown bean seedlings was lower with a dairy manure amendment versus an amendment with composted dairy manure (30). Foliar disease in cucumber was shown to respond to soil amendment with composted plant material (31).

The integration of relevant cultural methods with disease-forecasting models into tomato production systems offers a potential means to reduce the reliance on calendar-based spraying. The objectives of

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this study were to compare foliar disease levels, defoliation, and productivity in fresh-market tomato grown in (i) bed strategies representing varying levels of on- and off-farm inputs, (ii) spray programs representing varying levels of fungicide input, and (iii) combinations of bed strategies and spray programs. Factors affecting disease incidence in beds without fungicide have been reported in a previous article (16).

MATERIALS AND METHODS

Field site establishment. The study was conducted at the South Farm of the Henry A. Wallace Beltsville Agricultural Research Center in Beltsville, MD from 1997 to 1999. Beds in all plots were 15 cm in height, 0.9 m across, with 1.5 m between bed centers. Four bed strategies were evaluated, including uncovered beds with or without a composted dairy manure amendment and covered beds mulched

with either black polyethylene or hairy vetch residue. Beds in hairy vetch plots were formed in mid-September and seeded with hairy vetch at 45 kg/ha inoculated with a commercial preparation of *Rhizobium* spp. In April of each year, composted dairy manure, which was produced at Beltsville, was incorporated into soil of the appropriate plots at a rate of 15 metric tons/ha. Beds then were formed in all plots other than those with vetch. Black polyethylene and drip irrigation lines were installed on designated beds. All bare-soil surfaces then were treated with the pre-plant herbicide napropamide (Devrinol DF, 1.68 kg a.i./ha).

On 28 May 1997, 27 May 1998, and 19 May 1999, the vetch plots were mown with a high-speed flail mower positioned 5 cm above the bed surface. Mowing killed the vetch and created a layer of organic mulch throughout the entire plot surface (3). On the day following mowing each year, 6-

week-old seedlings of two cultivars commonly used in the northeastern United States, 'Mountain Pride' and 'Sunbeam', were transplanted mechanically with a distance of 0.38 m between transplants in each row. A 1-liter solution of Peter's Plant Starter fertilizer (9:45:15 N-P-K at 0.28 kg per 100 liters of water) was applied with each transplant. The seedlings had been treated with the insecticide imidacloprid (Admire 2 Flowable, 0.0952 g a.i. per seedling) before transplanting to manage Colorado potato beetle (*Leptinotarsa decemlineata* Say).

Drip irrigation was used to irrigate and fertigate. The weekly irrigation rate was 3.8 cm. Beginning in June of each year, there were four applications of urea, which occurred at 3-week intervals. Total urea application was 100 kg/ha for hairy vetch plots and 200 kg/ha for plots with uncovered or black polyethylene-covered beds. These rates duplicated the N requirements previously determined for the black polyethylene, hairy vetch, and uncovered bed systems (2). Metribuzin (Lexone DF, 0.50 kg a.i./ha) was applied in June to manage weeds emerging after crop establishment. Manual weeding occurred when necessary.

Fungicide spray programs. The spray programs were no fungicide, weekly fungicide applications, and applications scheduled according to the TOMCAST disease predictor based on a disease severity value (DSV) interval of 20 (21,22). Using the TOMCAST program, initial fungicide application occurred on 18 July 1997, 27 June 1998, and 14 June 1999. TOMCAST scheduled four (1997), five (1998), and six (1999) applications. The weekly spray program began on 18 July 1997, 27 June 1998, and 3 July 1999 when fruit were approximately one-third of their final diameter. There were 8 applications in 1997 and 10 applications in 1998 and 1999 using the weekly program.

Chlorothalonil (BRAVO Weatherstik, 2.25 kg a.i./ha) was applied exclusively in 1997 and 1999. Chlorothalonil was used primarily in 1998, although there was a single application of a mixture of chlorothalonil and propamocarb-HCL (Tattoo C, 3.30 kg a.i./ha) in response to local reports of late blight. Also in 1998, the harvest schedule dictated three applications of azoxystrobin (Quadris, 0.10 kg a.i./ha) due to its shorter preharvest interval compared with chlorothalonil.

Disease. Disease, which resulted from natural inoculation, was assessed weekly. Separate disease assessments were made for early blight and Septoria leaf spot in 1998 and 1999. The presence of pycnidia within Septoria leaf spot lesions enabled these lesions to be distinguish from early blight lesions. Five plants in the interior row of each subplot were selected for disease assessment. Five leaflets from the lower, middle, and upper canopy regions of each plant were scored for the percentage

Fig. 1. Early blight disease progress curves in 1997 for **A**, each bed strategy without fungicide application and **B**, each spray program averaged over all bed strategies. Cultivar data were combined. Disease severity is the percentage of symptomatic leaflet area.

of lesioned area. The disease severity estimates for the lower, middle, and upper canopy regions were averaged to compute final disease severity per leaflet. Based on the trapezoidal method (5), the mean value of weekly disease severity per leaflet was used to compute the area under the disease progress curve (AUDPC) value for each subplot.

Visual estimates of defoliation per plant were made during the growing season. The percentage of defoliation per plant was estimated weekly for the same five plants used for disease assessment. To compute the area under the defoliation curve (AUDC), the mean values of weekly defoliation for each subplot were summed using the trapezoidal method (5). The AUDC value was intended to quantify the magnitude of defoliation during the growing season.

Harvest. Yields were determined weekly. In all, 14 (1997 and 1998) and 12 (1999) plants from the interior row of each subplot were harvested. Fruit at the pink stage of development and beyond were harvested. Harvest commenced at the onset of ripening and continued until marketable fruit was no longer produced. All harvested fruit were scored for marketability, enumerated, and weighed. Marketability was based on fruit diameter, shape, and

general appearance. Mean fruit weight was calculated by dividing total marketable fruit weight by total marketable fruit number.

Experimental design. Treatments were randomized in a split-block design. Bed strategies were the main plots. There were six beds in each 43-by-10-m bed strategy. Each bed strategy was split by planting three adjacent beds with 'Mountain Pride' and the remaining three adjacent beds with 'Sunbeam'. The three fungicide programs traversed each block perpendicular to the bed strategies. Thus, each bed strategy–fungicide–cultivar subplot consisted of three beds, 14.3 m long. There were three replications in 1997 and four replications in 1998 and 1999.

Analysis of variance was performed on yield data, the AUDPC value, and the AUDC value using the PROC MIXED procedure of SAS (ver. 6.12). Means were separated by Fisher's protected least significant difference test. Due to similar disease and defoliation levels for the two cultivars, AUDPC and AUDC results were pooled across cultivars for the bed strategy and fungicide program treatments.

RESULTS

Disease. The 1997 early blight disease progress curves (Fig. 1) showed a delay in

epidemic onset and a reduction in severity in plots with hairy vetch. The AUDPC value for early blight was significantly lower ($P = 0.0006$) in plots with hairy vetch-covered beds (AUDPC = 173) compared with plots with uncovered (AUDPC = 450), uncovered and compost-amended (AUDPC = 411), or black polyethylene (AUDPC = 402) beds. Early blight occurred each year, whereas Septoria leaf spot occurred in 1998 and 1999. There was a significant bed strategy–fungicide program interaction (Table 1) for early blight and Septoria leaf spot in 1998 and 1999. This was due to lower AUDPC values in plots with black polyethylene or hairy vetch mulch compared with plots with uncovered beds when no fungicide was used (Table 2).

Across all bed strategies in 1997, early blight was significantly lower ($P = 0.0001$) under the weekly (AUDPC = 59) and TOMCAST (AUDPC = 60) programs compared with no fungicide application (AUDPC = 359) (Fig. 1). Early blight and Septoria leaf spot were managed effectively with fungicide (Table 2). The level of disease suppression across all bed strategies was similar with the TOMCAST and weekly fungicide programs each year (Table 2).

Table 1. Analysis of variance results (P values) for each study year^y

Variables ^z	AUDPC/early blight			AUDPC/Septoria leaf spot			AUDC			Marketable yield		
	1997	1998	1999	1997	1998	1999	1997	1998	1999	1997	1998	1999
Bed strategy	0.0006	0.0050	0.0001	...	0.0179	0.0001	0.0074	0.0004	0.0015	0.0400	0.1900	0.0200
Cultivar	0.9121	0.0002	0.5921	...	0.6012	0.0237	0.4692	0.0300	0.3589	0.0100	0.0050	0.1000
Fungicide	0.0001	0.0001	0.0001	...	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.2000	0.2200
Bed–cult	0.2960	0.3531	0.5135	...	0.7380	0.1569	0.1904	0.4977	0.6060	0.2000	0.0500	0.0900
Bed–fung	0.2122	0.0500	0.0001	...	0.0053	0.0001	0.0001	0.0001	0.0005	0.3900	0.2400	0.1800
Cult–fung	0.3666	0.2845	0.7151	...	0.7454	0.0082	0.3060	0.0225	0.3129	0.0400	0.3300	0.7000
Bed–cult–fung	0.7529	0.8932	0.6472	...	0.8737	0.1265	0.5490	0.6336	0.6724	0.4200	0.4300	0.4600

^y AUDPC = area under the disease progress curve and AUDC = area under the defoliation curve.

^z Bed strategy (bed) consisted of uncovered beds with or without a composted dairy manure amendment and beds covered with either black polyethylene or hairy vetch mulch. Cultivar (cult) consisted of cvs. Mountain Pride or Sunbeam. Fungicide (fung) consisted of no fungicide, weekly fungicide, or application scheduled using TOMCAST.

Table 2. Area under the disease progress curve (AUDPC) value for the early blight (EB) and Septoria leaf spot (SLS) epidemics and the area under the defoliation curve (AUDC) value^x

Bed strategy ^y	Fungicide ^z	AUDPC				AUDC		
		EB		SLS				
		1998	1999	1998	1999	1997	1998	1999
Compost	None	79 a	147 a	452 a	173 a	2,147 b	1,407 a	854 a
Uncovered	None	68 a	98 a	475 a	137 a	2,614 a	1,059 a	939 a
Polyethylene	None	43 b	45 b	347 b	0 b	2,558 ab	521 b	548 b
Hairy vetch	None	14 b	0 c	291 b	0 b	1,170 c	43 c	526 b
Compost	Weekly	3 b	1 c	69 c	1 b	471 de	2 c	90 c
Uncovered	Weekly	3 b	0 c	83 c	0 b	375 de	9 c	114 c
Polyethylene	Weekly	3 b	0 c	55 c	0 b	357 de	5 c	105 c
Hairy vetch	Weekly	2 b	0 c	43 c	0 b	155 c	0 c	66 c
Compost	TOM	9 b	1 c	51 c	0 b	722 d	10 c	66 c
Uncovered	TOM	5 b	0 c	48 c	0 b	333 de	6 c	83 c
Polyethylene	TOM	4 b	0 c	40 c	0 b	504 de	0 c	99 c
Hairy vetch	TOM	4 b	0 c	37 c	0 b	84 e	11 c	37 c

^x Means in the same column followed by the same letter do not differ at $P \leq 0.05$ according to the LSD test.

^y Compost = uncovered and amended with composted dairy manure; uncovered = uncovered and not amended with composted dairy manure; polyethylene = covered with black polyethylene mulch; hairy vetch = covered with hairy vetch mulch.

^z Fungicide programs: none = no fungicide application; TOM = the TOMCAST program; weekly = the weekly fungicide program.

AUDPC values were similar for Mountain Pride and Sunbeam, with two exceptions. The AUDPC value for early blight was greater for Mountain Pride in 1998 and for Septoria leaf spot in Sunbeam in 1999 (F was significant at $P < 0.05$). These cultivar differences in 1998 and 1999 were small and were not consistent.

Defoliation. Each year there was a significant bed strategy–fungicide program interaction for the AUDC value (Table 1). This interaction in 1997 resulted from less defoliation in plots with hairy vetch-covered beds compared with the other plots when no fungicide was applied (Table 2). In 1998 and 1999, this interaction was due to less defoliation in plots with mulch-covered beds compared with uncovered beds when no fungicide was applied.

Marketable yield. There were significant differences in marketable yield among bed strategies in 1997 and 1999 but not in 1998 (Table 1). Marketable yield in 1997 was greater in plots with mulch-covered beds compared with plots with uncovered beds (Table 3). Marketable yield in 1999 was greater in plots with beds covered with black polyethylene compared with hairy vetch mulch. Mean fruit weight was significantly lower in plots with hairy vetch-covered beds compared with the other plots in 1999 (*data not shown*). The percentage of marketable fruit harvested did not differ significantly among bed strategies in any year.

Across all bed strategies, there were no significant differences in marketable yield in any year under the weekly or TOMCAST programs, but marketable yield was greater in plots where fungicide was applied compared with plots without fungicide in 1997, with a similar trend in 1998 and 1999. Marketable fruit percentage and mean fruit weight showed similar results (*data not shown*).

Marketable yield was higher in Sunbeam compared with Mountain Pride in 1997 and 1998, with a similar trend in 1999 (Table 3). Sunbeam tomatoes had a higher percentage of marketable fruit number and mean fruit weight than Mountain Pride in every year (*data not shown*). The cultivar–fungicide program interaction for marketable yield was significant in 1997

due to greater yield for Sunbeam than for Mountain Pride when no fungicide was applied.

DISCUSSION

More severe epidemics were observed in plots with uncovered beds compared with mulched beds. This was associated with greater soil particle deposition on tomato foliage following rainfall in plots with uncovered beds compared with mulched beds (16). Less soil deposition on tomato foliage in beds mulched with black polyethylene or hairy vetch suggests that inoculum dispersal was less effective in mulched beds. A reduction of inoculum dispersal may have contributed to lower disease severity in plots with mulched beds.

Early blight and defoliation was lower in plots with hairy vetch-covered beds compared with plots with other bed strategies in 1997. There was greater rainfall during 1997 compared with 1998 or 1999 (*data not shown*), suggesting that hairy vetch residue may reduce disease more effectively than the other bed strategies in years when rain-driven inoculum dispersal is highest. This is consistent with less splash dispersal of soil observed in the hairy vetch plots in 1997 (16). Previous research showed that tomato plants grown in hairy vetch-covered beds have greater leaf area than plants grown in beds covered with black polyethylene mulch (28). The combination of less defoliation and greater leaf area has prolonged the duration of marketable fruit production in regions with an extended growing season.

The trend toward higher yields in the hairy vetch than in the other bed strategies in 1997 and 1998 conform with reports of greater yield for tomato grown in beds with hairy vetch mulch compared with black polyethylene mulch or uncovered beds (1,3). However, the lower marketable yield observed in plots with hairy mulch in 1999 contrasts sharply with these earlier findings. Lower marketable yield in hairy vetch-covered beds in 1999 was associated with unusually dry conditions before and after transplanting. Thus, the soil water assimilated by the rapidly growing cover crop in the spring of 1999 was not replenished by rainfall, leaving the beds excessively dry during plant establishment. With little rain and lack of overhead irrigation, the rate of cover crop decomposition and, consequently, N availability in plots with hairy vetch-covered beds also was probably diminished in 1999. It is likely that drip irrigation, alone, provided insufficient water and nutrient delivery to tomatoes grown in hairy vetch-covered beds in 1999. In dry years, overhead irrigation before and after transplanting may be necessary to ensure consistent productivity in hairy vetch-covered beds. More research is needed to determine the specific irrigation requirements of the hairy vetch system.

The similar suppression of disease and defoliation as well as the similarity in yield by the weekly and TOMCAST spray programs parallels earlier findings (8,12,25). Approximately half as many applications were required by the TOMCAST as by the calendar-based spray program. Other studies have documented fewer fungicide sprays when using TOMCAST compared with calendar-based programs (8,12,25). Similar levels of foliar disease, defoliation, and yield were observed among all bed strategies under the TOMCAST or weekly fungicide spray programs. Therefore, a lower-input system, including TOMCAST, which could lower fungicide applications, integrated with a hairy vetch cover crop, which could lower nitrogen and herbicide applications, might compare favorably with a high-input system based on black polyethylene mulch and weekly spraying. Lower disease severity with hairy vetch mulch in 1997 suggests that the TOMCAST spray interval could be extended in the vetch system, further reducing inputs. However, lower yield in the hairy vetch system in 1999 underscores the need to characterize this system further in order to achieve reliable production and profitability in dry years.

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Table 3. Marketable yield for each bed strategy, fungicide scheduling program, and cultivar

Treatment	Total marketable yield (kg/ha) ^z		
	1997	1998	1999
Hairy vetch	102,899 a	101,861 a	58,873 b
Black polyethylene	99,307 a	99,446 a	82,970 a
Compost	96,793 ab	93,205 a	71,278 ab
Uncovered	90,107 b	89,461 a	69,771 ab
Weekly	102,425 a	98,316 a	73,825 a
TOMCAST	102,434 a	96,553 a	72,342 a
No fungicide	86,971 b	93,111 a	66,002 a
'Sunbeam'	100,358 a	99,585 a	73,607 a
'Mountain Pride'	94,195 b	92,404 b	67,839 a

^z Means for the treatment and year followed by the same letter are not significantly different at $P = 0.05$ according to the least significant difference test.

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