Effects of Management Practices and Fungicides on Sooty Blotch and Flyspeck Diseases and Productivity of Liberty Apples

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ABSTRACT

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Effects of tree spacing, ground cover management, and summer fungicides on the incidence and economic impacts of sooty blotch and flyspeck (SBFS) were evaluated over four seasons in a high-density planting of Liberty apples by determining disease incidence, number of fruit produced, total yield, pack-out, and potential gross returns for each treatment. Tree spacing and ground cover management had no effect on the incidence of SBFS on fruit in the upper tree canopy. Disease incidence on fruit from the lower tree canopy was unaffected by tree spacing but was reduced slightly by careful ground cover management. Fungicides applied during summer consistently reduced the incidence of SBFS in both the upper and lower canopy area. Sprayed trees defoliated approximately 2 weeks later in October than unsprayed trees each year. Return bloom was not affected by fungicide treatment, but fruit-set efficiency, number of fruit produced, total harvested yield, and estimated gross return per ha were higher in the plots receiving fungicides than in those receiving no fungicides. Plots treated with fungicides had 11.6% greater mean yield and 50% greater gross returns than untreated plots. Possible reasons for the premature defoliation and reduced fruit set on trees receiving no fungicides are discussed.

Additional keywords: *Geastrumia polystigmatis, Leptodontidium elatius, Peltaster fructicola, Schizothyrium pomi, Zygophiala jamaicensis*

Sooty blotch on apples (*Malus* × *domestica* Borkh.) is caused by several different fungi including *Peltaster fructicola* Johnson, *Leptodontidium elatius* (G. Mangenot) De Hoog, and *Geastrumia polystigmatis* Batista & M. L. Farr (10). Flyspeck is caused by *Schizothyrium pomi* (Mont. & Fr.) Arx, the anamorph of *Zygophiala jamaicensis* E. Mason. Sooty blotch and flyspeck (SBFS) cause superficial, dark-colored blemishes on the skin of apple fruit. Severely affected fruit are virtually unmarketable except for juice, and multiple small infections exclude fruit from Fancy or Extra Fancy grades according to USDA grading standards (4). Apple growers selling fresh market fruit currently apply fungicides at varying intervals from late May through August to control SBFS.

SBFS are both favored by warm humid summer weather and are the most common summer diseases on apple throughout the eastern United States. SBFS are more severe in southern than in northern production areas. However, incidence of these diseases has increased in New York and New England during the past 7 years as apple growers changed their fungicide strategies (7). During this period, many growers reduced fungicide use during summer in response to political and economic pressures. At the same time, other constraints caused growers to stop using certain fungicides that have the best activity against SBFS. From 1975 to 1985, combinations of benomyl plus mancozeb or thiophanate-methyl plus mancozeb were used throughout the season in many orchards in New York. Benomyl, thiophanate-methyl, and mancozeb were all highly effective against flyspeck. However, early-season use of benomyl declined when benzimidazole-resistant strains of apple scab appeared in New York orchards in the mid 1980s. Mancozeb lost its label for summer sprays on apples in 1990. Flyspeck became a serious commercial problem in New York and New England when growers switched from combinations of mancozeb with a benzimidazole fungicide to fungicides with no activity or only limited activity against SBFS. The apple scab fungicides fenarimol and myclobutanil provide no control of SBFS. Captan and thiram, fungicides that are used during summer instead of mancozeb, have only limited residual activity against SBFS (17).

SBFS are controlled with fungicides in commercial orchards, but some cultural management techniques have also been suggested. Development of SBFS has been correlated with periods of high relative humidity and with accumulations of hours of leaf wetness (6,22,25). SBFS can be reduced if apple trees are pruned to enhance rapid drying after rains and dews (8, 15). Keeping the grass between tree rows well-mowed and allowing more space between trees have also been recommended as ways to speed drying and reduce relative humidity (17,19). However, there is no experimental evidence that regular orchard mowing and wider tree spacing results in less SBFS. The objective of this study was to determine how various disease management strategies applied to Liberty apples would affect incidence of SBFS, total yield, fruit size and grade, and gross returns. Scab-resistant cultivars such as Liberty are ideal for studying SBFS because they require no early-season apple scab fungicides that might confound studies involving summer diseases. Preliminary results from this research were published previously (13,18,20,21).

MATERIALS AND METHODS

An experiment was initiated in 1991 to evaluate the impact of tree spacing, ground cover management, and summer fungicides on incidence of SBFS in a high-density planting of Liberty apples. The experiment was designed as a 2 × 2 × 2 factorial with four replicates in a blocked design.

The Liberty trees on M.9 EMLA rootstock were planted in 1987. Trees were spaced 3.05 m between rows and 0.91 m within rows except that each five-tree plot was separated within rows by a 1.83 m space. Trees were trained as modified slender spindles. Galvanized conduit poles extending 2.35 m aboveground were used to support trees. The tops of the poles were attached to a high-tensile wire stretched along the rows. By the end of the experiment, many trees had fruiting leaders that extended 0.9 to 1.2 m higher than the support poles, and fruit was harvested using step ladders.

In spring of 1991, every third row in the planting was removed and, in half of the plots, every other tree within the row was removed. Removal of every third row left a double-row system with a drive-row 6.10 m wide between double rows. The drive-row width was an artifact of the original row spacing in the orchard. A more logical drive-row width for the double-row plant-

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ing design would have been 4.88 m. We therefore used 4.88 m as the drive-row width for calculating the number of trees and yield per hectare represented by this planting. For the low-tree-density plots where trees were removed within the row, final tree spacing was 1.83 m between trees and 3.05 m between double rows for a tree density of 1,379 trees per ha. In the high-tree-density plots, trees within rows were not removed, and tree density was calculated as 2,301 trees per ha. Average spacing in the high-density plots was 1.10 m within rows because there was 0.91 m between each of five trees and 1.83 m between plots. Because of the wider spacing between plots, trees at the ends of the plots were slightly larger and more productive. Therefore the extra space between plots was included in calculating mean tree spacing. For both tree densities, individual plots were composed of sections of the double rows that were 5.49 m in length. High-density plots consisted of 10 trees (five in each row) and low-density plots consisted of six trees (three in each row).

The variable for ground cover management involved both frequency of mowing the row middles and the width of the herbicide strip beneath trees. Half of the plots had a 1-m herbicide strip with row middles mowed five to eight times per year whereas the other half had a 0.3-m herbicide strip with row middles mowed only one to three times per year. In 1991 and 1992, the latter plots were mowed only in late June, before harvest in September, and again in late October. In 1993 and 1994, the late-June mowing was also eliminated and grass was allowed to grow until the preharvest mowing in August or September. In close-mowed plots, the grass ground cover both between the double rows and in the drive-rows was mowed with a commercial walk-behind lawnmower. Herbicide treatments were recommended rates of glyphosate plus simizine plus diuron applied in combination in spring with follow-up applications of glyphosate alone in late summer. In 1993 and 1994, mean grass height in each plot was measured at weekly intervals through the summer.

The fungicide factor in the experiment involved leaving half of the plots unsprayed all year while the other half received applications of fungicide during June, July, and August. All sprays were applied dilute with a handgun. Fungicides used in this experiment were benomyl (Benlate 50DF and Benlate 50W, E. I. DuPont de Nemours Co., Wilmington, DE), captan (Captan 50W, Zeneca Ag Products, Wilmington, DE), thiophanate-methyl (Topsin M 85WDG, Atochem North America Inc., Philadelphia, PA), and ziram (Ziram 76W, Atochem North America Inc., Philadelphia, PA). Sprayed plots received benomyl 75 mg a.i./liter plus captan 600 mg a.i./liter on 14 June, 7 July, and 8 August 1991; thiophanate-methyl 191 mg a.i./liter plus captan 600 mg a.i./liter on 10 June, 6 July, and 19 August 1992; thiophanate-methyl 191 mg a.i./liter plus ziram 912 mg a.i./liter applied on 8 and 24 June, 22 July, and 16 August 1993; benomyl 113 mg a.i./liter plus captan 600 mg a.i./liter applied on 9 June, 6 July, and 1 and 24 August 1994.

To ensure uniform distribution of inoculum within the orchard, wild blackberry canes with visible infections of SBFS were collected each year from local sources, cut to 30-cm lengths, and tied into four trees in each test plot. The inoculum was introduced into the trees 7 to 14 days after the apple trees had reached petal fall.

In late October of 1991, we noted that trees that had been left unsprayed throughout the summer were completely defoliated whereas trees receiving monthly fungicide sprays still had healthy green foliage. Trees were evaluated for percentage of defoliation in mid and late October each year from 1992 through 1994 by counting leaves and leaf scars on the current season's shoot growth on 20 arbitrarily selected terminals from each of three different trees in each plot. In 1992, defoliation was also assessed by comparing the number of spur leaves remaining on each of 20 spurs for three trees in each plot.

The density of flower clusters was evaluated each spring from 1992 through 1994 by counting all flower clusters on a marked scaffold limb in both the lower and upper canopy portions of the trees. The lower canopy limbs were 0.6 to 1.2 m above ground whereas the upper canopy limbs were 1.2 to 1.8 m aboveground. Limbs selected were average size for the trees involved, but limbs that had been severe pruned in previous years were avoided. Fruit on the same limbs were counted in late June or early July after chemically thinned fruit had dropped. Fruit set efficiency was determined by dividing the number of fruit per limb by the number of clusters per limb. All trees were chemically thinned by applying 10 μg of napthalene acetic acid (NAA; Fruitone N, Rhone-Poulenc, Inc., Monmouth Junction, NJ) per ml on 28 May 1992, 10 μg NAA per ml plus 600 mg a.i. of carbaryl (Sevin 50W, Rhone-Poulenc, Inc., Monmouth Junction, NJ) per liter on 18 May 1993, and 15 μg NAA per ml plus 600 mg a.i. of carbaryl per liter on 20 May 1994. Chemical fruit thinners were applied with a handgun.

Total yield was determined by harvesting, counting, and weighing (in bulk) all fruit from each plot in 1991, 1993, and 1994, and all fruit from one row in each plot in 1992. Harvesting was done when fruit were at commercial harvest maturity between 15 and 26 September. Each year, subsamples of fruit from each plot were individually weighed, graded for color and defects, and evaluated for SBFS. The subsample consisted of 100 fruit per plot in 1991, 100 fruit each from the lower and upper canopy in each plot in 1992, and 50 fruit each from the lower and upper canopy in each plot in 1993 and 1994. Premature fruit drop during the 2 weeks before harvest was determined for each plot by removing all fruit from beneath trees in early September and then again after harvest. The fruit removed after harvest were considered "premature drops" and the proportion of the total crop they represented was determined by dividing the number of premature drops per plot by the sum of harvested plus dropped fruit.

Following harvest and grading in 1992 through 1994, the potential gross dollar-return per ha was calculated for each treatment. Individual fruit weights were converted to market sizes using weight-to-size conversion factors used by a Hudson Valley packinghouse to program their computer-controlled weight-sizer for packing Empire (Table 1). The actual market value of Liberty is not known because Liberty has never been sold in enough volume to determine a fair market value for packed and graded fruit. We therefore used market prices received for the variety Empire to estimate the potential value of Liberty. A large apple sales corporation in the Hudson Valley provided the mean sales prices for Empire apples for the 1989 to 1990 and 1990 to 1991 marketing seasons in various size and grade categories (Table 1). To determine the projected dollar-return per ha

Table 1. Relationships between standard market sizes, fruit weight, and prices, reported for Empire apples and used for economic analyses of potential returns for Liberty apples

Standard size	Weight range (g)	Dollar value per box (18.14 kg) for fruit in the Fancy or Extra-Fancy grades[a]
Bags	85.2 to 107.7	$ 8.00
163 count	107.8 to 119.1	9.00
150 count	119.2 to 130.4	10.00
138 count	130.5 to 141.8	10.00
125 count	141.9 to 155.9	11.00
113 count	156.0 to 175.8	13.00
100 count	>175.8	16.00

[a] Based on estimates provided by a major Hudson Valley apple sales group for average prices received for various sizes of Empire apples sold during the 1989 to 1990 and 1990 to 1991 marketing years. Fruit unsuitable for the Fancy/Extra-Fancy combination pack were sold either as U.S. No. 1 grade ($6.00 per box regardless of size) or as culls for making juice ($2.00 per box). All fruit smaller than 85.2 g were valued as culls.

Table 2. Effects of three management variables on the incidence of sooty blotch and flyspeck and on proportions of fruit down-graded from the highest quality pack because of these diseases

Management variable	Fruit with flyspeck (%)				Fruit with sooty blotch (%)				Fruit not meeting standards for U.S. Fancy grade because of flyspeck and sooty blotch (%)			
	1992	1993	1994	Grand means	1992	1993	1994	Grand means	1992	1993	1994	Grand means
Upper limbs												
Tree density												
1,379 trees/ha	46.7	2.0	6.5	14.0	9.0	0.2	1.9	2.6	30.7	1.8	6.1	10.1
2,301 trees/ha	50.0	1.7	10.5	16.3	8.5	0.3	4.3	3.5	36.1	1.6	11.6	13.3
Ground cover												
Close-mowed	49.4	1.3	10.3	15.7	7.9	0.1	3.3	2.8	34.1	1.4	9.8	12.0
Unmowed	47.3	2.4	6.8	14.6	9.5	0.4	2.7	3.2	32.7	2.1	7.6	11.4
Fungicide program												
Summer fungicides	33.5*[a]	<0.1*	1.4*	6.1*	1.4*	0.0*	<0.1*	0.2*[b]	20.7*	0.0*	1.0*	3.6*[b]
Unsprayed	63.3	6.6	20.6	27.3	21.3	1.0	10.4	8.9	47.6	6.7	22.9	23.6
Lower limbs												
Tree density												
1,379 trees/ha	76.0	5.8	41.3	38.3	31.4	2.4	25.2	17.1	66.5	6.0	49.5	37.7
2,301 trees/ha	78.2	8.1	41.2	40.5	35.1	3.2	31.6	20.5	68.7	8.5	48.0	39.4
Ground cover												
Close-mowed	74.5	4.6	32.7*	33.9*	30.1	1.9	18.0*	14.1*[c]	65.8	4.7	39.1*	33.1*
Unmowed	79.6	9.7	50.8	45.0	36.4	3.9	40.0	23.8	69.3	10.3	58.3	44.1
Fungicide program												
Summer fungicides	59.1*	0.9*	9.3*	17.2*[b]	8.6*	0.0*	0.7*	1.6*[b]	45.8*	0.5*	9.8*	13.6*[b]
Unsprayed	91.1	17.8	78.1	64.2	64.5	10.9	74.1	48.5	86.0	20.5	88.6	67.3

[a] Asterisks indicate cases in which the management variables had a significant ($P < 0.05$) effect on the means as determined with a factorial analysis with repeated measures. The arcsin-square root transformation was used for analysis of percentages. Upper limbs and lower limbs were analyzed independently. Grand means are the means for 3 years.

[b] There was a significant ($P < 0.05$) year × fungicide interaction in the repeated measures analysis for this variable.

[c] There was a significant ($P < 0.05$) year × ground cover interaction in the repeated measures analysis for this variable.

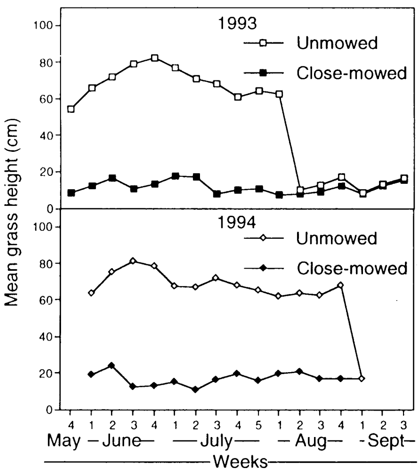

Fig. 1. Mean grass height in close-mowed and unmowed plots as measured at weekly intervals during 1993 and 1994.

for the various treatments, total yield for each plot was multiplied by the proportion of apples in each size/grade category as determined by grading the harvested subsample of fruit from that plot. The results were then multiplied by the sales value for the various sizes and grades, the total returns for all sizes/grades were summed to determine the total value per plot, and the value per plot was multiplied by the number of plots required to fill 1 ha.

Results of the factorial experiment for the 1992 through 1994 seasons were statistically analyzed with the statistical design for repeated measures wherein each year represented a repeated measure of the same plots. Analyses were completed with the SuperAnova (version 1.11) statistical package (Abacus Concepts, Inc., Berkeley, CA).

RESULTS

Statistical analysis of the variables measured in this experiment revealed few significant interactions between tree spacing, ground cover management, and summer fungicides. Therefore, results are discussed in terms of differences between grand means for the 2 × 2 × 2 factorial experiment. For all years and variables measured, the incidence of SBFS was significantly ($P < 0.05$) greater for lower limbs than for upper limbs. The mean incidence of flyspeck across all treatments and years was 40% for lower limbs compared with 16% for upper limbs.

Tree density had no effect on the incidence of SBFS (Table 2). Ground cover management had a significant ($P < 0.05$) effect only on lower limbs. Within years, the effect of ground cover was significant only in 1994. Differences in grass height between close-mowed and unmowed plots were similar in 1993 and 1994, but the annual preharvest mowing of the "unmowed" plots was done earlier in 1993 than in 1994 (Fig. 1).

Of the three variables evaluated in this experiment, summer fungicides had the largest and most consistent effect on the incidence of SBFS. Fruit from sprayed trees had significantly less SBFS than fruit from unsprayed trees in every year. In 1991, incidences of flyspeck and sooty blotch were 1.6 and 0%, respectively, for sprayed plots, compared with 28.6 and 5.3% for unsprayed plots. From 1992 through 1994, the incidence of SBFS was quantified separately for upper and lower limbs of the trees. Fungicide treatment had a significant effect on disease incidence in both parts of the tree canopy (Table 2). Dry weather during the summer of 1993 resulted in a low incidence of SBFS whereas wet weather in 1992 and 1994 favored unusually severe infection. The limited number of fungicide applications we used did not provide adequate control of SBFS in the wet summers of 1992 and 1994.

Sprayed trees defoliated approximately 2 weeks later than unsprayed trees each year. Defoliation of sprayed trees in late October was roughly equivalent to defoliation of unsprayed trees in mid October (Table 3). In 1993, trees spaced at the higher density defoliated significantly earlier than trees at the lower density spacing, but there were no tree spacing effects in 1992 and 1994.

Return bloom (as determined by blossom counts on selected limbs) was not affected by fungicide treatment in any of the comparisons (Table 4). Return bloom on lower limbs was better in low-density plots than in high-density plots during 1992 and 1993, but there were no differences in 1994. Mowed plots had slightly more flowers per limb than unmowed plots in 1992 but not in any other year.

Table 3. Grand means from factorial analyses showing impacts of tree spacing, ground cover management, and summer fungicide sprays on premature defoliation of Liberty apple trees

Management variable	No. of leaves remaining on spurs 15 October 1992	Percent defoliation of terminal shoots					
		1992		1993		1994	
		October 15	October 27[a]	October 14[b]	October 26	October 19	October 28
Tree density							
1,379 trees/ha	2.5	20.2	54.5	15.0*[c]	32.4*	13.0	30.7
2,301 trees/ha	2.2	23.8	57.7	19.9	40.1	14.3	34.9
Ground cover							
Close-mowed	2.4	22.1	56.9	16.9	38.2	12.3	30.1
Unmowed	2.3	21.8	55.3	17.9	34.3	15.0	35.2
Fungicide program							
Summer fungicides	3.3*	10.6*	40.1*	14.2*	23.4*	11.2*	21.8*
Unsprayed	1.4	36.0	71.4	20.6	50.2	16.4	45.5

[a] There was a significant ($P < 0.05$) ground cover × tree density interaction for the analysis of percent defoliation on 27 October 1992.
[b] There was a significant ($P < 0.05$) fungicide × ground cover interaction for the analysis of percent defoliation on 14 October 1993.
[c] Asterisks indicate cases in which the management variables had a significant ($P < 0.05$) effect on the means as determined with factorial analysis. The arcsin-square root transformation was used for analysis of percentages.

Mean fruit-set efficiency over 3 years was higher in the plots receiving fungicides than in those receiving no fungicides with significant ($P < 0.05$) differences in only 1 of 3 years for upper limbs but in 2 of 3 years for lower limbs (Table 4). The number of fruit produced per plot was also greater in fungicide-treated trees for 2 of the 4 years (Table 5). However, because sprayed trees carried more fruit than unsprayed trees in 1992, the sprayed trees produced fewer large fruit (Table 6). Fruit size was also affected by tree density with a higher percentage of large fruit in the low-density than in the high-density plots (Table 6). The mean incidence of premature fruit drop over 4 years was significantly greater for low-density than for high-density plots and for close-mowed than for unmowed plots (Table 5). However, fungicide treatment had no consistent effect on the incidence of preharvest drop.

For fruit graded to USDA standards, the mean returns per hectare across all plots in the experiment were $10,492, $7,768, and $17,338 for 1992, 1993, and 1994, respectively. Returns ranged from a high of $26,872/ha in the high-density, close-mowed, fungicide-treated plots in 1994 to a low of $5,673/ha in the low-density, unmowed, unsprayed plots in 1993. Mean returns over 3 years were significantly greater ($P < 0.05$) for high-density plots ($13,163/ha) than for low-density plots ($10,566/ha) with significant differences between yearly means only in 1992. Ground cover management did not have any effect on projected returns in any of the three years.

Table 4. Effects of three management variables on return bloom and fruit set efficiency in Liberty apple trees on M.9 EMLA rootstock

Management variable	No. of blossom clusters per limb[a]				Fruit-set efficiency[b]			
	1992	1993	1994	Grand means	1992	1993	1994	Grand means[c]
Upper limbs								
Tree density								
1,379 trees/ha	15.6	11.7	22.2	16.5	0.85	0.87	0.51	0.75*[d]
2,301 trees/ha	16.0	10.5	21.4	16.0	0.77	0.75	0.52	0.68
Ground cover								
Close-mowed	17.1*	10.8	21.5	16.5	0.88*	0.83	0.50	0.69
Unmowed	14.5	11.4	22.1	16.0	0.75	0.79	0.54	0.74
Fungicide program								
Summer fungicides	16.2	10.7	24.1	16.8	0.87*	0.87	0.53	0.76*
Unsprayed	15.5	11.6	19.5	15.7	0.75	0.75	0.51	0.67
Lower limbs								
Tree density								
1,379 trees/ha	47.4*	16.6*	36.6	33.5*	0.71	0.90	0.57	0.73*
2,301 trees/ha	34.4	12.2	30.3	25.6	0.64	0.79	0.54	0.66
Ground cover								
Close-mowed	44.2*	13.6	35.5	31.1	0.65	0.92*	0.56	0.71
Unmowed	37.5	15.1	31.4	28.0	0.69	0.77	0.55	0.67
Fungicide program								
Summer fungicides	40.9	13.2	32.1	28.7	0.75*	0.96*	0.59	0.76*
Unsprayed	40.9	15.5	34.8	30.4	0.60	0.74	0.52	0.62

[a] Means were determined by counting all clusters on marked limbs (upper and lower canopy) on each of six trees in each plot on 1 May 1992, 5 May 1993, and 9 May 1994.
[b] The fruit set efficiency was determined by counting all fruit on designated limbs on 13 July 1992, 28 June 1993, and 23 June 1994 and by dividing the number of fruit per limb by the number of flower clusters per limb.
[c] There were significant ($P < 0.05$) ground cover × fungicide × year interactions in the repeated measures analysis of fruit-set efficiency for both upper and lower canopy limbs.
[d] Asterisks indicate cases in which the management variables had a significant ($P < 0.05$) effect on the means as determined with a factorial analysis with repeated measures. The arcsin-square root transformation was used for analysis of percentages. Upper limbs and lower limbs were analyzed independently. Grand means are the means for 3 years.

Mean returns over 3 years were significantly greater ($P < 0.05$) for plots treated with fungicides ($14,236) compared with unsprayed plots ($9,494). The yearly means for fungicide-treated compared with unsprayed plots were significantly ($P < 0.05$) different in 1992 and 1994. Fungicide treatments resulted in a total increase over 3 years of $14,226 in projected returns per ha. If more stringent fungicide programs had been used in 1992 and 1994 so that SBFS would have been completely controlled, then the 3-year mean for the annual value of the crop from fungicide-treated plots would have been $15,251 and the accumulated difference between fungicide sprayed and unsprayed plots over 3 years would have been $17,271 per ha.

The reduced returns for unsprayed compared with fungicide-sprayed plots were mostly attributable to SBFS that caused downgrading of unsprayed fruit. However, fungicide-treated plots produced better returns than unsprayed plots even when returns were calculated without downgrading fruit that had SBFS. When SBFS was ignored in the grading, mean returns over 3 years were $15,251 for fungicide-treated plots compared with $13,902 for unsprayed plots, and the means were significantly different ($P = 0.05$).

DISCUSSION

Severity of SBFS in this trial was enhanced by the inoculum introduced on blackberry canes and by the natural susceptibility of Liberty apple to these summer diseases. However, the hill-top location and small trees in this test orchard allowed more rapid drying than might have occurred in larger trees or in a site with less air drainage and less exposure to wind. Considering all factors, the amount of disease that developed in our plots was probably consistent with what would occur in many commercial orchards in the area. Addition of inoculum was essential to minimize edge effects and ensure that the amounts of inoculum present in each plot were reasonably similar.

Effects of ground cover management were significant only in the lower tree canopy and then only in 1994 and in the analysis of combined data from all 3 years. Thus, we found limited evidence to support the assumption that ground cover management plays a role in incidence and severity of SBFS. Effects of ground cover management were most evident in 1994 because it was a wet year and the grass in unmowed plots was not trimmed at all until late August. Ground cover management had no significant effect on disease incidence in 1992 when the unmowed plots were trimmed once during June or in 1993 when dry weather slowed development of SBFS.

Fungicide treatment had a consistent and significant effect on incidence of SBFS in both the lower and upper tree canopy. However, neither the three fungicide sprays applied during 1992 nor the four applications in 1994 were adequate to control SBFS during those wet seasons. In 1992, the extended interval between fungicide applications on 6 July and 19 August allowed SBFS to become established and develop on fruit. In 1994, accumulated rains of 11.7 and 14.7 cm occurred between applications on 9 July and 1 August and between 1 and 14 August, respectively. These heavy rains reduced or eliminated the residual activity of the fungicides and allowed SBFS to become established.

Despite our failure to completely control SBFS, the benefits of the fungicides were significant. The total cost for the fungicides used on sprayed trees averaged less than \$123/ha/year. Total costs for the fungicide program would have included another \$37/ha per application to cover the costs of labor and equipment depreciation involved in making the applications. Thus, the maximum cost for the summer fungicide treatments would have been \$271/ha/year (\$123 for fungicides plus costs for 4 applications at \$37 each). The \$271/ha/year invested in summer fungicides produced an average difference in returns between sprayed and unsprayed plots of \$4,742 or a return of \$17.50 for each dollar spent on fungicides and application costs.

Considerable premature fruit drop occurred in all treatments, but none of the treatments had any consistent affect on premature drop. Premature drop increased rapidly as fruit approached maturity. Thus, there was more premature drop in 1991 when we harvested later in September than in other years when harvest was initiated earlier. The higher premature drop observed in low-tree-density plots and in mowed plots over 3 years (Table 5) may reflect earlier fruit ripening in these plots than in the comparable high-density and unmowed plots. Greater competition for light and water in the high-density and unmowed plots may have slowed ripening in these plots.

Tree density and ground cover management had various interesting effects not directly related to disease incidence. As expected, plots with high tree density were more productive than low-density plots (Table 6), but the difference diminished

Table 5. Effects of three management variables on numbers of fruit harvested and on incidence of preharvest fruit drop in a block of Liberty apples on M.9 EMLA rootstock

	Total number of fruit produced per plot					Premature fruit drop (%)				
Management variable	**1991**	**1992**	**1993**	**1994**	**Grand means[a]**	**1991**	**1992**	**1993**	**1994**	**Grand means[b]**
Tree density										
1,379 trees/ha	409*[c]	762*	850	1,424*	861*	36.0*	18.4	19.8	12.5	21.1*
2,301 trees/ha	714	1,102	994	1,856	1,166	28.6	15.1	16.1	11.7	17.5
Ground cover										
Close-mowed	489	946	865	1,736*	1,009	34.4	17.2	21.0	15.2*	21.6*
Unmowed	634	918	979	1,544	1,019	30.0	16.2	15.1	9.3	17.1
Fungicide program										
Summer fungicides	599	1,004*	981	1,727*	1,078*	28.7*	16.9	16.3	13.8*	18.5
Unsprayed	523	861	863	1,553	950	35.9	16.5	19.6	10.5	19.9

[a] In the repeated measures analysis, the following interactions were significant ($P < 0.05$): year × ground cover, year × tree density, fungicide × ground cover × tree density.
[b] In the repeated measures analysis, the following interactions were significant ($P < 0.05$): year × fungicide, fungicide × ground cover × tree density.
[c] Asterisks indicate cases in which the management variables had a significant ($P < 0.05$) effect on the means as determined with a factorial analysis with repeated measures. Grand means are the means for 3 years. The arcsin-square root transformation was used for analysis of percentages.

Table 6. Effects of three management variables on total production per hectare and on the proportion of fruit reaching larger size categories

	Yield (excluding preharvest drops) (tons/ha)					Percent of fruit that could be packed as 125-count or larger (>141.8 g/fruit)			
Management variable	**1991**	**1992**	**1993**	**1994**	**Grand means[a]**	**1992**	**1993**	**1994**	**Grand means[b]**
Tree density									
1,379 trees/ha	8.14*[c]	31.78*	19.44	42.84*	25.56*	25.2*	37.6	54.3*	38.9*
2,301 trees/ha	15.11	45.90	22.97	55.50	34.88	14.5	31.2	45.1	29.7
Ground cover									
Close-mowed	10.07	38.93	19.72	50.89*	29.89	19.3	38.3	50.3	35.6
Unmowed	13.18	38.74	22.69	47.45	30.51	19.8	30.6	49.1	32.7
Fungicide program									
Summer fungicides	13.09	40.25	22.97	51.17*	31.87*	15.0	32.5	51.1	32.2
Unsprayed	10.17	37.42	19.44	47.17	28.58	24.6*	36.1	48.2	36.1

[a] There was a significant ($P < 0.05$) year × fungicide interaction in the repeated measures analysis for this variable.
[b] There was a significant ($P < 0.05$) year × tree density interaction in the repeated measures analysis for this variable.
[c] Asterisks indicate cases in which the management variables had a significant ($P < 0.05$) effect on the means as determined with a factorial analysis with repeated measures. Grand means are the means for 3 years.

each year from 1991 to 1993 as the trees in low-density plots gradually filled more of the space between trees. In 1992 and 1993, the lower limbs in high-density plots had fewer flowers than lower limbs in low-density plots (Table 3), probably because the lower limbs in low-density plots had better light exposure. Good light exposure increases the likelihood that spurs will form blossom buds. By 1994, the trees in low-density plots had expanded to fill more of their available space, the tops of the trees had grown larger, and the effect of tree density on flowering in the lower limbs was no longer significant. Fruit-set efficiency in 1993 was greater in mowed than in unmowed plots (Table 3), but reasons for this difference were not evident.

The most unexpected observations in this experiment were the earlier defoliation, reduced fruit-set efficiency, and lower yield in unsprayed trees. The early defoliation in unsprayed plots was related to leaf-spotting that appeared each year in mid to late September. Foliage on sprayed and unsprayed trees showed no visual differences prior to mid September. Then, within several weeks, leaves on unsprayed trees developed irregular leaf spots on their upper surfaces. The leaf spotting appeared evenly distributed throughout the tree and throughout the unsprayed plots. Several weeks after the leaf spotting appeared, leaves turned yellow and began to abscise. By late October, differences between sprayed and unsprayed trees were evident even when plots were observed from a considerable distance because most leaves had fallen from trees in unsprayed plots. Similar leaf spotting and defoliation were observed in a nearby plot where Golden Delicious had been left unsprayed, but the leaf spotting was less severe. No early defoliation was noted on unsprayed McIntosh in the same plots. Thus, there may be varietal differences in susceptibility to the late-season leaf-spotting phenomenon.

The cause of the late-season leaf spotting remains undetermined. Numerous isolations made in 1992 and 1994 produced a mixture of common weak pathogens: *Botryosphaeria obtusa*, *Phomopsis* and *Phoma* spp., and other unidentified filamentous fungi (D. A. Rosenberger, unpublished). No single organisms predominated in these isolations.

The early defoliation, reduced yield, and reduced fruit-set efficiency in unsprayed trees may have all resulted from either direct or from indirect effects of fungicides on apple tree physiology. We used a benzimidazole fungicide each year, and at least one of the benzimidazoles (benomyl) is known to have some cytokinin-like activity (5,23). Benomyl also protects plants from ozone damage (11,12,14). High ozone levels occur sporadically in the Hudson Valley during summer, but ozone damage probably was not a significant factor in the early defoliation.

In other cropping systems, fungicides have been shown to improve yield even in the absence of disease by virtue of their impact on nonpathogenic leaf microflora. In barley, unsprayed plants challenged with a nonpathogenic fungus produced phytoalexins that apparently reduced the ability of the plant to produce seed (24). The nonpathogenic fungus was prevented from germinating and did not elicit phytoalexins in fungicide-treated barley plants. "Tonic sprays" of fungicides applied to coffee result in increased yields, possibly because they control leaf microflora that either produce ethylene themselves or stimulate ethylene production and early senescence in the coffee leaves (26). The common constituents of apple leaf microflora and their population dynamics have been extensively studied (2,3,16), and some of the impacts of fungicides on apple leaf microflora have been documented (1,9). However, no one has determined if large microflora populations extract energy from their host plants and might thereby contribute to reduced yields. We suspect that a highly precocious and productive apple cultivar like Liberty grafted to a dwarfing, efficient rootstock like M.9 EMLA may have such limited reserve capacity that even minor stresses, such as those that might result from foliar microflora, could cause small reductions in yield like those noted in this experiment. More research is required to determine if fungicide-microflora interactions have an impact on productivity in apples.

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