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Incidence of Diseases on Foliage of Nine Apple Genotypes as Influenced by Six Fungicide Treatments

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Abstract

Three commercially important apple cultivars ('Delicious,' 'Golden Delicious' and 'York'), three scab-immune cultivars ('Liberty,' 'Redfree,' and 'Freedom'), and three scab-immune numbered selections from New York were subjected to six different fungicide/timing treatments for three years to evaluate their effects on resulting foliar disease symptoms. Apple scab *(Venturia inaequalis)* infections occurred only on 'Delicious,' 'Golden Delicious' and 'York' and were prevented by early-season fungicide sprays. Leaf spot symptoms were not identified by cause and could include frogeye leaf spot *(Botryosphaeria obtusa)*, early symptoms of Alternaria blotch *(Alternaria mali)* or early phases of rust infections on resistant genotypes. Leaf spot symptoms were generally most severe on 'Redfree' and NY 74840-1 and least severe on 'Golden Delicious' and NY 74828-12. Necrotic leaf blotch was observed on 'Golden Delicious' each year. The percentage of leaves that had abscissed by late Aug. was greatest for 'Golden Delicious' (probably due to necrotic leaf blotch), 'Redfree,' and NY 73334-35 (possibly due to cedar apple rust or Alternaria blotch). These results indicate that foliage of scab-immune genotypes may possess varying susceptibility to other diseases.

Introduction

The apple industries in most developed countries are under pressure to produce high quality fruit while minimizing the use of agricultural chemicals. Apple breeders from North America and Europe have responded to this challenge by selecting genotypes with resistance to

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some diseases. Since 1970 over 20 scab immune cultivars have been released. Some of these cultivars also have resistance to cedar-apple rust *(Gymnosporangium juniperi-virginianae)*, powdery mildew *(Podosphaera leucotricha)*, and/or fire blight *(Erwinia amylovora)*, but breeders have not selected for resistance to quince rust *(G. clavipes)*, hawthorne rust *(G. globosum farl)*, black rot *(Botryosphaeria obtusa)*, bitter rot *(Colletotrichum gloeosporioides)*, white rot *(Botryosphaeria dothidea)*, sooty blotch *(Gloeodes pomigena)*, fly speck *(Schizothyrium pomi)*, Brooks fruit spot *(Mycosphaerella pomi)*, black pox *(Helminthosporium papulosum)*, and Alternaria blotch *(Alternaria mali)* which can be devastating in the southeastern U.S. and can result in 100% crop loss. During the 1980s, Sutton (11) evaluated seven scab-immune cultivars at three locations in North Carolina and reported that all were susceptible to the summer diseases and most were not adapted to the warmer, eastern part of the state. Sutton suggested that if some loss from rot is acceptable, then fungicide sprays could be applied to these cultivars at 3 to 4 week intervals beginning at petal fall.

Environmental conditions in Virginia are generally less favorable for summer disease development than those in North Carolina, but some disease problems are usually more severe than in areas where apple breeding programs, with the exception of Arkansas, are located. Therefore, Virginia is a good location to evaluate the relative susceptibility of apple cultivars to summer diseases. The purpose of this study was to determine if apple genotypes, known to vary in susceptibility to early-season diseases, can be grown in Virginia with reduced reliance on fungicides. In this report we present data for incidence of disease on the foliage.

Methods

In May 1993, 270 trees on M.9 rootstock were planted at the Virginia Tech College of Agriculture and Life Science Kentland Farm near Blacksburg, VA. The factorial experiment consisted of nine genotypes and six fungicide treatments (Table 1) in a split-plot design with five replications. Each replicate (whole-plot) consisted of six groups (subplot) of nine trees, to which fungicide treatments were assigned randomly. Trees, one per genotype, were randomized within each subplot. Fungicides were sprayed to runoff with a single nozzle backpack sprayer. The same trees were assigned to the same treatment during 1994 and 1995. Treatments were modified in 1996, but the same control trees were left untreated for all three years. Trees were supported to 2m with a wooden post and were trained as central leaders with minimal pruning. A 1.5m-wide herbicide strip was maintained under the trees. When necessary to adjust crop load, trees were hand thinned. Insecticides (mostly Guthion, Imidan, and Lannate) were applied to control insects on all trees on the same dates as fungicides were applied. To ensure high disease pressure, cedar-apple rust galls, quince rust cankers and dead apple twigs, colonized by rot fungi, were placed in small cages attached to the tops of each post at about tight cluster.

In 1994 and 1995 fungicide treatments were selected that would differentially control various diseases. Early-season triadimefon treatment was selected to provide moderate control of apple scab, and good control of powdery mildew and rusts. Early-season syllit treatment was expected to give good control of apple scab, but poor control of powdery mildew and rusts. Late-season treatment with benomyl plus captan was expected to provide good control of sooty blotch and fly speck, fair control of black rot and white rot, and moderate control of bitter rot. In 1995 early-season diseases were not serious, but none of the treatments adequately controlled fruit rots, so in 1996 early-season sprays of mancozeb plus myclobutanil were applied to control all early-season diseases. The late-season combination of captan, benomyl, and ziram was compared to captan plus benomyl for control of rots. Each year late-sea-

Table 1. Dates of early- and late-season (cover sprays) fungicide treatments applied to nine apple genotypes for two seasons.

Treatment date	Time of season	Fungicide treatment[z] 1	2	3	4	5	6
			1995				
27 March; 10, 25 April	Early	None	None	T	S	T, S	T, S
15, 23 May; 5, 29 June; 12 July; 9, 25 Aug.	Late	None	C, B	None	None	None	C, B
			1996				
11, 25 April; 6 May	Early	None	None	None	M, P	M, P	M, P
14, 22, 30 May; 11, 26 June; 8, 23, 31 July; 14, 28 Aug.	Late	None	C, B	C, B, Z	None	C, B	C, B, Z

[z]Fungicides, AI/liter: captan (C), Captan 50W (0.6g/l); benomyl (B), Benlate 50W (0.11 g/l); triadimefon (T), Bayleton 50DF (0.037 g/l); syllit (S), Dodine G5W (0.4 g/l); myclobutanil (M), Nova 40W (0.06 g/l); mancozeb (P), Penncozeb 80W (0.96 g/l); ziram (Z), Ziram 76DF (0.91 g/l).

son treatments were applied alone or in combination with early-season treatments to determine if early-season treatments would improve the control of late-season diseases.

Foliar disease symptoms were evaluated on 2 Aug. 1994, 20 June and 29 Aug. 1995, and 17 July 1996. Three current-season shoots per tree were selected. For each shoot the total number of leaves and the numbers of leaves with lesions of apple scab, cedar-apple rust , leaf spot, and necrotic leaf blotch were recorded and expressed as a percentage of the total leaves per shoot. The number of lesions per leaf was not recorded. Necrotic leaf blotch, a common physiological disorder of 'Golden Delicious' in the mid-Atlantic region, causes relatively large irregularly shaped necrotic areas on leaves followed by chlorosis of most of the leaf and eventually, abscission. Older leaves, especially at the tree interior, are most susceptible and one or more waves of leaf abscission may result in 50% defoliation by harvest (12). The term "leaf spot" is used to refer to round necrotic lesions that may have been caused by captan injury, black rot (frog-eye leaf spot), Alternaria blotch, or early phases of rust infections on resistant genotypes because it is not possible to visually distinguish among these four causes of leaf spot early in the season, and isolating the causal agent from lesions is difficult. Because trees treated with captan had no more leaf spot than other trees, the symptoms likely were caused by one of the fungi. To assess disease-induced leaf abscission, the number of nodes without leaves was recorded on 29 Aug. 1995. A hygrothermograph, located about 0.3 km from the planting, was used to continuously record temperature and relative humidity. Periods of 100% relative humidity were assumed to be wetting periods. Daily precipitation was measured with a rain gauge. Length of wetting period and average temperature during the wetting period were used to determine light, moderate, or heavy apple scab infection periods from Jones' modification of the Mills table (1).

Statistical analyses. Data were evaluated with analysis of variance using SAS's Mixed Procedure (9). Genotypes and fungicide treatments were specified as fixed effects, whereas replicates, shoots nested in trees, and interaction terms containing replicates were specified as random effects. Because a few trees died, there were missing observations and Least Square (LS) means are presented. Because SAS procedures do not correctly calculate degrees of freedom when there are missing observations, Satterthwaite's formula (10) was used to calculate approximate degrees of freedom by includ-

Table 2. LS means for percentage of leaves with various disease symptoms as influenced by genotype and fungicide treatments in 1994.

Factor[z]		Cedar-apple rust	Leaf spot	Necrotic leaf blotch	Abscissed leaves %
Fungicide Treatment					
Early	*Late*				
None	None	2.6	19	3	1
None	C,B	1.9	19	5	2
T	None	2.7	19	3	1
S	None	1.9	17	5	2
T,S	None	2.4	21	6	2
T,S	C,B	2.1	17	4	2
Genotype					
Delicious		0.1c	32 a	0 b	0 b
Golden Del.		5.8 b	13 d	37 a	14 a
York		14.1 a	24 b	0 b	0 b
Freedom		0.0 c	13 d	0 b	0 b
Liberty		0.0 c	19 c	1 b	0 b
Redfree		0.1 c	24 b	0 b	0 b
NY 74840-1		0.0 c	24 b	0 b	0 b
NY 74828-12		0.0 c	11 d	0 b	0 b
NY 73334-35		0.0 c	11 d	0 b	0 b
Significance[y]					
Treatment		NS	NS	NS	NS
Genotype		**	**	**	**
Interaction		NS	NS	**	NS

[z]Fungicides: T = triadimefon, S = syllit, C = captan, B = benomyl. Chemical rates are presented in Table 1.
[y]LS mean separation within factor and column by multiple t-test (a = 0.0014).
NS = not significant, ** = significant, 1% level.

ing the ddfm=satterth Option in the Model statement (5). When the genotype x treatment interaction was significant ($P < 0.05$) the LS means for treatments within each genotype and for genotypes within each treatment were compared, using the Slice option in the model statement with multiple t-tests. To avoid experiment-wise error rate inflation, the P-value for each pair-wise comparison was adjusted using Bonferroni's Simultaneous Confidence Interval Procedure ($\alpha = 0.05$/no. of comparisons) (4).

Results

Date of full bloom varied across genotypes; full bloom for 'Delicious' occurred on 28 April 1995 and 17 April 1996 and fungicide treatments were applied based on the phenology of 'Delicious.'

1994. May and June were extremely dry, so environmental conditions were poor for early-season disease infection. From 1 April through 4 June there were eight occasions when leaves were wet for more than nine hours, and temperatures were adequate for light apple scab infection during only five of those wetting periods. Fungicide treatments minimally affected foliar disease symptoms in 1994 (Table 2), but genotypes differed significantly for all diseases evaluated except scab (scab data not presented). Apple scab developed only on 'Delicious' and 'York' trees not sprayed with syllit in the early season. The genotype x treatment interac-

Table 3. LS means for disease symptoms on leaves of nine apple genotypes treated with six fungicide programs. Leaves were evaluated 20 June, 1995.

Genotype	Treatment Time Early / Late	Fungicide program[z] 1 None / None		2 None / C,B		3 T / None		4 S / None		5 T,S / None		6 T,S / C,B	
		Cedar-apple rust (%)											
Delicious		0a[yx]	B	0a	B	0a	B	0a	B	0a	B	0a	C
Golden Del.		31a	A	27ab	A	3c	B	18b	A	4c	B	5c	B
York		33a	A	28a	A	14bc	A	20b	A	13c	A	9c	A
Freedom		0a	B	0a	B	0a	B	0a	B	0a	B	0a	C
Liberty		0a	B	0a	B	1a	B	0a	B	0a	B	0a	C
Redfree		0a	B	0a	B	0a	B	0a	B	1a	B	0a	C
NY 74840-1		0a	B	0a	B	0a	B	0a	B	0a	B	0a	C
NY 73334-12		0a	B	0a	B	0a	B	0a	B	0a	B	0a	C
NY 73334-35		0a	B	0a	B	0a	B	0a	B	0a	B	0a	C
		Leaf spot (%)											
Delicious		17a	EF	6bc	C	11ab	B	11ab	D	14a	BC	3c	E
Golden Del.		12a	F	7a	C	1a	B	13a	D	7a	C	6a	CDE
York		11a	F	13a	C	16a	B	13a	D	18a	B	12a	BCD
Freedom		23a	DE	22a	B	14b	B	20a	CD	13b	BC	5c	DE
Liberty		30a	BCD	23ab	B	17b	B	18b	CD	17b	B	15b	B
Redfree		41a	A	30b	AB	21bc	B	26b	BC	26b	A	14c	BC
NY 74840-1		25bc	CDE	33ab	A	36a	A	33ab	AB	28ab	A	17c	B
NY 73334-12		32ab	BC	27bc	AB	18cd	B	37a	A	17d	B	13d	BC
NY 73334-35		35a	AB	33a	A	18c	B	37a	A	29ab	A	24bc	A
		Leaves abscissed (%) by 29 Aug.											
Delicious		14a	EF	0b	D	16a	CD	10ab	C	17a	E	0b	C
Golden Del.		36a	B	13b	A	31a	AB	35a	A	28a	BCD	16b	A
York		25bc	CD	8c	B	23c	BC	35a	A	32ab	BC	6c	BC
Freedom		22a	CDE	1c	CD	11ab	DE	16a	BC	17a	E	2bc	BC
Liberty		17a	DE	1b	CD	16ab	CD	17a	BC	20a	DE	6b	BC
Redfree		31a	BC	5b	BC	27a	B	25a	B	24a	CDE	6b	BC
NY 74840-1		7a	F	2b	CD	6a	E	9a	C	7a	F	1B	BC
NY 74828-12		47a	A	7b	B	39a	A	43a	A	46a	A	6b	BC
NY 73334-35		30ab	BC	2c	CD	26b	B	24b	B	35a	B	7c	B

[z]Fungicides: T = triadimefon, s = syllit, C = captan, B = benomyl. Chemical rates are presented in Table 1.
[y]Values are LS means of 15 shoots per treatment combination.
[x]Genotype by fungicide treatment interactions were significant ($P < 0.05$). LS mean separation across rows (lower case letters) and down columns (upper case letters) by multiple t-test, $\alpha = 0.0038$ and 0.0014 respectively.

tion was significant only for leaf blotch. Powdery mildew was not observed on any leaves during the three years of this study.

Cedar-apple rust was most severe on 'York' and moderate on 'Golden Delicious.' In general, leaf spot was most severe on 'Delicious,' NY 74840-1, 'York' and 'Redfree' and least severe on 'Golden Delicious,' NY 74828-12, NY 73334-35, 'Liberty' and 'Freedom.' Leaf blotch was

Table 4. LS means for percentage of leaves with leaf spot on 19 July 1996 for nine apple genotypes sprayed with six fungicide treatments.

	Fungicide treatment[z]											
Treatment Time	1		2		3		4		5		6	
Early	None		None		None		M, P		M, P		M, P	
Genotype Late	None		C, B		C, B, Z		None		C, B		C, B, Z	
Delicious	10a	BC	12a	B	15a	B	10a	B	9a	AB	3a	A
Golden Del.	4a	C	5a	B	6a	C	3a	B	2a	B	2a	A
York	13a	BC	16a	AB	8ab	BC	21a	A	13a	A	3b	A
Freedom	11ab	AB	18a	AB	17a	AB	1b	B	5b	AB	1b	A
Liberty	4a	C	8a	B	3a	C	4a	B	1a	B	1a	A
Redfree	14ab	A	22a	A	19a	AB	8b	B	2b	B	2b	A
NY 74840-1	17ab	A	25a	A	21ab	A	11b	AB	7b	AB	6b	A
NY 73334-12	5a	BC	9a	B	3a	C	5a	B	3a	B	1a	A
NY 73334-35	11b	BC	18a	AB	10b	BC	9b	B	8b	AB	1c	A

[z]Fungicides: P = penncozeb, M = myclobutanil, C = captan, Z = ziram, B = benomyl.
[y]Values are LS means of 15 shoots per treatment combination. The genotype x fungicide interaction was significant ($P < 0.05$). LS means were separated across rows (lower case letters) by multiple t-test ($\alpha = 0.0033$) and down columns (upper case letters) by multiple t-test ($\alpha = 0.0014$).

severe on 'Golden Delicious,' slight on 'Liberty,' and absent on all other genotypes. Early leaf abscission occurred only on 'Golden Delicious.'

1995. The interaction of genotype x treatment was significant for all diseases except apple scab and leaf blotch, and interaction means are presented in Table 3. Precipitation was plentiful in April and May, and there were four light, two moderate, and two severe infection periods for apple scab. However, only 0.2 and 0.1% of the 'Delicious' and 'Golden Delicious' leaves, respectively, had scab symptoms (data not shown) and other cultivars had no scab symptoms. Necrotic leaf blotch was most severe on 'Golden Delicious' (9% infected leaves), and was present on 0.1 to 0.4% of the leaves for 'Freedom,' 'Liberty,' 'Redfree,' NY 74840-1, and NY 73334-35, but was not observed on other genotypes (data not shown).

Only 'York' and 'Golden Delicious' exhibited cedar-apple rust symptoms, which were significantly reduced by early-season triadimefon applications (Treatments 3, 5, 6) (Table 3). Triadimefon was more effective on 'Golden Delicious' than 'York.' Early-season syllit applications (Treatment 4) marginally suppressed rust.

For nontreated trees, leaf spot was greatest on NY 74828-12, NY 73334-35, 'Redfree,' and 'Liberty,' whereas 'Delicious,' 'Golden Delicious,' and 'York' had the least (Table 3). Early-season treatments with triadimefon (Treatments 3, 5, and 6) provided marginal leafspot control on 'Freedom,' 'Liberty,' 'Redfree,' NY 73334-35, and NY 74828-12, but not on other genotypes. Treatment 2 (late season captan plus benomyl) significantly reduced leaf spot on 'Delicious.' Compared to the nonsprayed control, the full-season program (Treatment 6) significantly reduced leaf spot on all genotypes except 'York.'

Nonsprayed 'Delicious,' 'Liberty' and NY 74840-1 had less than 20% leaf abscission in late Aug., whereas 'Golden Delicious,' 'Redfree,' NY 74828-12 and NY 73334-35 had at least 30% abscission. Late-season treatments containing captan plus benomyl (Treatments 2 and 6) reduced abscission to less than 10% for all genotypes except 'Golden Delicious.' Treatments lacking late-season captan plus benomyl (Treatments 3, 4 and 5) generally had leaf abscission similar to the control. Leaf abscission on 'Golden Delicious' was likely caused by necrotic leaf blotch, which is marginally controlled by the EBDC fungicides (13). Some of the leaf spot symptoms observed in June may have been caused by Alternaria blotch. 'Delicious,' which is very susceptible to this fungus (12), had 17% leaf spot infection in June and 14% leaf abscission in August. Other genotypes where the percentages of leaves with spot symptoms in June apparently related to the percentage of abscissed leaves in Aug. included 'Freedom,' 'Redfree,' NY 74828-12, and NY 73334-35. The susceptibility of these genotypes to Alternaria blotch needs to be evaluated.

1996. During April and May there were five light, three moderate, and three heavy infection periods for apple scab. Apple scab lesions were observed on no more than 5% of the leaves of 'Delicious,' irrespective of treatment (data not shown). The cultivar x treatment interaction was significant (P = 0.03) for leaf blotch, but only 'Golden Delicious' had more than 1% of the leaves with symptoms (data not shown). For 'Golden Delicious,' leaf blotch symptoms were most severe on Treatment 4 (18%), but because only 4 and 5% of the leaves had symptoms for Treatments 1 and 6, respectively, leaf blotch severity did not seem to be related to treatment (data not shown). Cedar-apple rust was observed only on 'Golden Delicious' (27%) and 'York' (36%) trees that did not receive early-season fungicide treatments (Treatments 1-3), but early-season treatment with myclobutanil plus mancozeb (Treatments 4-6) reduced infection to no more than 2% (data not shown).

For nontreated trees, leaf spot was greatest on 'Redfree' and NY 74840-1, intermediate on NY 73334-35 and 'Freedom,' and least on 'Golden Delicious' and 'Liberty" (Table 4). Compared to the nontreated control, early-season application of myclobutanil plus mancozeb (Treatment 4), reduced leaf spot except on 'Delicious,' NY 74828-12, 'Golden Delicious,' 'Liberty,' and 'York.' Compared to the nontreated control, late-season applications of captan plus benomyl or captan, benomyl, and ziram (Treatments 2 & 3) significantly reduced leaf spot on only 'Redfree.' All nontreated trees except 'Golden Delicious' and 'Liberty' had > 10% leaf spot, but all trees receiving the full-season programs (Treatments 5 and 6) had < 14% leaf spot. Addition of ziram (Treatment 3 and 6) to late-season captan plus benomyl applications (Treatments 2 and 5) generally, but not often significantly, reduced leaf spot.

Discussion

Because apple scab and powdery mildew symptoms have not been serious on any trees on this farm, inoculum levels apparently are low. Before clearing the land and planting fruit trees in 1988, this orchard site was in hardwood trees. Although there are scattered yard trees within one km, there are no commercial orchards within 20 km of our research orchard. Apple trees apparently have not been grown on this isolated site long enough to develop high levels of apple scab or powdery mildew

Of the genotypes evaluated in this study, only 'Golden Delicious' and 'York' appeared susceptible to cedar-apple rust and early-season fungicide treatments provided good control. Leaf blotch symptoms observed in this study were likely caused by necrotic leaf blotch because symptoms were limited to 'Golden Delicious' and, as previously reported (13) the fungicides used in this study provided little control.

Of the disease symptoms observed in this study, leaf spot was the most prevalent and was most affected by genotype and treatment. As indicated earlier, leaf spotting may have been caused by black rot, cedar apple rust, or Alternaria leaf blotch. Rust-induced leaf spotting can cause severe damage to leaves of rust-resistant cultivars in areas where rust inoculum is abundant (14). In New York nonsprayed 'Freedom,' 'Liberty,' NY 74828-12 and NY 7334-35 trees had more than 30% leaves with spotting (8). Leaf abscission can occur when leaves have more than five lesions per leaf (6). Black rot caused severe leaf spotting on 'Redfree' and symptoms were less severe on 'Delicious' (15). Black rot may not have been the primary cause of leaf spot in our study because captan (Treatments 2 and 6 in 1994 and 1995, and Treatments 2, 3, 5, and 6 in 1996) should have provided good control (3). Rosenberger et al. (7) also reported leaf spot development in mid- to late-Sept. followed by early defoliation on nonsprayed, but not sprayed, 'Liberty' trees. The cause of the leaf spotting was not determined, but a mixture of common weak pathogens (*Botryosphaeria obtusa*, *Phomopsis* and *Phoma* spp.) were isolated (7). In our study the leaf spot phenomenon likely was caused by another organism because spotting occurred in June, 'Liberty' was not particularly susceptible, and fungicides did not totally eliminate the problem. In four states Yoder et al. (16) evaluated 23 apple cultivars, receiving minimal spray schedules, for foliar symptoms of apple scab, powdery mildew, cedar-apple rust, and leaf spots. They reported leaf spot incidence ranging from 22% for 'Senshu' to 1.4% for 'Goldrush.' The only cultivar common to their study and ours was 'Golden Delicious' which they found to be relatively resistant with 4.1% infection. Filajdic and Sutton (2) rated 30 cultivars for susceptibility to Alternaria blotch and found that 'Delicious' was the most susceptible and that strains of 'Delicious' varied in susceptibility. 'Freedom' ranked as the 10th most susceptible; 'York,' 'Golden Delicious,' 'Redfree,' and 'Liberty' ranked 11, 12, 13, and 14 respectively, whereas 'Akane' and 'Ginger Gold' were least susceptible (rankings of 29 and 30). Leaf spot results from our study generally agree with previous reports. Although relative symptom severity varied with season, 'Golden Delicious,' 'York,' and 'Liberty' and NY 74828-12 were generally least susceptible and 'Redfree' and NY 74840-1 were generally most susceptible.

Although scab-immune genotypes have been selected in northern areas and were selected for resistance to early-season diseases, some genotypes appear somewhat resistant to other diseases. 'Liberty' and NY 74828-12 appear fairly resistant to leaf spot, and 'Liberty' and NY 74840-1 had little premature leaf abscission. However, the severe leaf abscission and leaf spot symptoms observed on 'Freedom,' 'Redfree,' and NY 73334-35 may indicate susceptibility to Alternaria blotch.

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