Effect of Pruning on Apple Scab in Organic Apple Production

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ABSTRACT

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In a 3-year Hungarian study, the effectiveness of apple tree pruning as a management tactic for control of apple scab (*Venturia inaequalis*) was investigated on two susceptible (cvs. Jonagold and Mutsu), two moderately susceptible (cvs. Elstar and Idared), and two V_r resistant apple cultivars (cvs. Liberty and Prima) in three high-density organic apple orchards treated with copper- and sulfur-based fungicide programs. The area under the disease progress curve (AUDPC) for leaf and fruit incidences was calculated to evaluate three winter pruning treatments (unpruned, weakly pruned, and strongly pruned). Strong pruning significantly decreased leaf scab on the susceptible and the moderately susceptible cultivars at all sites compared with unpruned ones. Moreover, for the cultivar Jonagold in all years and for the cultivar Mutsu in 2001, AUDPC values of strongly pruned trees were significantly lower at $P = 0.05$ compared with the weakly pruned trees. The effect of pruning on development of fruit scab was weaker than on leaf scab in all years and at all sites. For fruit scab incidence on susceptible cultivars, only strong pruning treatments decreased AUDPC significantly compared with unpruned treatments. The effects of pruning treatments on moderately susceptible cultivars were significant only in 2001 at all sites. Resistant cultivars showed no significant effect of pruning treatments on development of either fruit or leaf scab except for cultivar Liberty in 2001 at one site. Pruning resulted in no consistent difference in the apple tree canopy microclimate. However, strong pruning resulted in improved spray deposition in the tree canopy when applications were made with an airblast sprayer at midsummer. Results are compared with similar studies, and their biological interpretation is discussed.

Additional keywords: cultural control, disease incidence, integrated pest management, plant canopy microclimate, potential ascospore dose, scab control

The fungus *Venturia inaequalis* (Cooke) G. Wint. (anamorph: *Spilocaea pomi* Fr.:Fr.) causes scab of apple (*Malus × domestica* Borkh.) and is common on apple leaves and fruits in temperate growing regions (29). Weather often provides suitable conditions for severe scab epidemics in Hungary, and 10 to 30% of apple fruits are consequently downgraded when marketed (16). Therefore, frequent fungicide applications (10 to 18 annually) are needed to control apple scab. As consumers increasingly demand apples free of chemical residues and as environmental considerations become more important, interest in organic fruit production is growing all over the world (9,10,35,37,45). The organization International Federation of Organic Agriculture Movements (IFOAM) and, recently, the U.S. Department of Agriculture through the National Organic Program (NOP) fully implemented their standards for organic crop production outlining the

criteria that must be met to label agricultural products as “organic” (23–25,37). According to both IFOAM and NOP standards, organic production allows products such as biologicals (*Trichoderma* spp.), minerals (soluble rock powder), elemental and lime sulfur, hydrated lime, and mechanical methods (trap). However, only a few approved fungicidal products are available for organic scab control, such as sulfur and copper compounds, and these are less effective and more phytotoxic than modern synthetic fungicides (6,10,17–19).

In order to lessen the risk of scab epidemics, research was begun to evaluate nonspraying management options (29), but tree pruning has received little attention in scab control. Tree pruning is performed primarily for modification of tree form for optimum production of high-quality apples. However, mechanical modification of the canopy can also alter the microclimate and prevent or abate disease (5,11,46); therefore, the authors concluded that pruning might also be a useful disease management option. The effect of pruning on the incidence of flyspeck and sooty blotch has been studied. Latham and Hollingsworth (27), Ocamb-Basu et al. (33), and Cooley et al. (4,5,7) observed that flyspeck and sooty blotch on apple often are more severe in unpruned trees than in pruned

ones. They suggested that pruning improves drying in the apple tree canopy and can be used to reduce the incidence of flyspeck or sooty blotch. No scientific study has been performed on the effect of pruning on apple scab. If pruning could reduce incidence of apple scab, it might also suppress scab development and epidemics in infested organic apple orchards, depending on cultivar susceptibility.

The aim of the 3-year study was to determine whether pruning has an effect on the development of apple scab under a continental climate, and if so, to determine how scab development is affected by the degree of pruning, cultivar susceptibility, and location in high-density organic apple orchards treated with copper- and sulfur-based fungicide programs. The effect of pruning on apple tree canopy microclimate and spray deposition was also studied.

MATERIALS AND METHODS

Orchard sites, plant materials, and spray schedules. The studies were conducted during 2000, 2001, and 2002 in three organic commercial apple orchards in Hungary. One of the orchards was located at 47°31'60"N and 21°37'60"E, in Nagykálló, Eastern Hungary. The other two orchards were in Debrecen-Józsa and Eperjeske, 33 km south and 89 km north of the orchard at Nagykálló, respectively.

In Nagykálló, the 3.2-ha orchard consisted of seven apple cultivars, with a minimum of 500 trees of each cultivar. This orchard consisted of 44 rows, with a distance between rows of 4 m and within a row of 1.5 m. In Debrecen-Józsa, the 12.5-ha orchard consisted of seven apple cultivars, with a minimum of 600 trees of each cultivar. This orchard consisted of 80 rows, with a distance between rows of 4 m and within a row of 1.5 m. In Eperjeske, the area of the orchard used in our study was 6.8 ha. It consisted of eight apple cultivars, with a minimum of 500 trees of each cultivar. This orchard consisted of 48 rows, with a distance between rows of 5 m and within a row of 2 m. In the three orchards, all trees were on M26 rootstocks and pruned to spindle shape and planted in 1996, except for Debrecen-Józsa, where trees were on M9 rootstocks.

Hungarian organic production guidelines (1) derived from the IFOAM standards (23,24) have been applied since the planting of all three orchards. Spray schedules against apple scab in 2000, 2001, and 2002 in the three orchards are given in Table 1.

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Selected cultivars and experimental design. Three cultivars, one V_f -resistant (scab resistance is conditioned by a single gene, designated V_f [47], with the V referring to *Venturia* and the f referring to the resistance source, *M. floribunda*), one moderately susceptible, and one susceptible to apple scab, were selected for the pruning treatments for each of the three orchards. The selected V_f -resistant cultivars (8,26) were Liberty at Nagykálló, and Prima at Debrecen-Józsa and Eperjeske; the moderately susceptible cultivars (16,32) were Elstar at Nagykálló and Debrecen-Józsa, and Idared at Eperjeske; and the susceptible cultivars (16,34) were Jonagold at Nagykálló and Debrecen-Józsa, and Mutsu at Eperjeske.

Three pruning treatments were performed from 2000 to 2002 in each of the three orchards. Treatments were in four replicates for each of the three cultivars. Each treatment replicate plot consisted of 14 trees at each site. As cultivars were in one block at each site, the pruning treatments were in a completely randomized design (CRD) for each cultivar and site (14). In treatment 1, trees were unpruned, in treatments 2 and 3, trees were weakly and strongly pruned, respectively. In treat-

ment 2, the crown of a tree was reduced to 90 to 95% by removing only 1-year-old twigs. In treatment 3, the crown of a tree was reduced to 75 to 80% by removing 1- and 2-year-old twigs and, if necessary, the 3-year-old twigs. Pruning was performed once a year in February, before bud break, in all three orchards (Table 2).

Potential ascospore dose. In spring, the potential ascospore dose (PAD) was calculated in each orchard according to Gadoury and MacHardy (12). The mean number of scab lesions per square meter of leaf at leaf fall (lesion density = LD) was recorded at the end of October in 1999, 2000, and 2001 (Table 2). The proportion of the or-

Table 2. Dates of sampling and pruning in the organic apple orchards at Nagykálló, Debrecen-Józsa, and Eperjeske, Hungary (1999-2002)

Location and season	LD ^y assessment	Pruning	LLD ^z assessment	Weather recording period
Nagykálló				
1999	25 October	...	...	...
2000	29 October	22 February	27 February	10 March to 11 October
2001	31 October	24 February	3 March	10 March to 14 October
2002	...	26 February	6 March	15 March to 15 October
Debrecen-Józsa				
1999	22 October	...	...	...
2000	31 October	15 February	27 February	11 March to 10 October
2001	27 October	25 February	1 March	20 March to 16 October
2002	...	23 February	25 February	15 March to 15 October
Eperjeske				
1999	27 October	...	...	...
2000	30 October	22 February	23 February	10 March to 10 October
2001	28 October	28 February	4 March	12 March to 15 October
2002	...	14 February	26 February	15 March to 11 October

^y Lesion density: lesion number per square meter of leaf.

^z Leaf litter density: proportion of orchard floor covered by leaf litter.

Table 1. Spray schedules against apple scab in the organic apple orchards at Nagykálló, Debrecen-Józsa, and Eperjeske, Hungary (2000-2002)

Nagykálló				Debrecen-Józsa				Eperjeske			
Date	Phenolog. stage	Trade name ^z	Dos.	Date	Phenolog. stage	Trade name ^z	Dos.	Date	Phenolog. stage	Trade name ^z	Dos.
2000				2000				2000			
4 Apr	Green tip	Cuproxat FW	0.1%	1 Apr	Green tip	Réxoxiklorid 50WP	0.3%	27 Mar	Green tip	Funguran-OH	0.1%
10 Apr	Tight cluster	Cuproxat FW	0.1%	12 Apr	Tight cluster	Réxkén 650FW	0.3%			Kumulus S	0.2%
26 Apr, 9, 16, 25 May, 2 Jun, 17 Jul	After tight cluster	Szulfur 900FW	0.4%	24 Apr, 11, 19, 27 May, 2, 11, 17 Jun, 17 Jul	After tight cluster	Kumulus S	0.4%	4 Apr	Tight cluster	Funguran-OH	0.1%
								12, 19, 26 Apr, 3, 11, 19, 27 May, 2, 11, 19, 27 Jun, 5, 21, 31 Jul, 12 Aug	After tight cluster	Kumulus S	0.2%
											0.4%
2001				2001				2001			
27 Mar	Bud break	Cuproxat FW	0.1%	29 Mar	Bud break	Réxoxiklorid 50WP	0.3%	26 Mar	Green tip	Funguran-OH	0.1%
5 Apr	Green tip	Cuproxat FW	0.1%	8 Apr	Green tip	Réxoxiklorid 50WP	0.3%			Kumulus S	0.2%
12, 19, 25 Apr, 11, 19, 27 May, 5, 15, 27 Jun, 19 Jul	After green tip	Szulfur 900FW	0.4%	15, 22, 30 Apr, 6, 18, 25 May, 4, 12, 21 Jun, 12 Jul	After green tip	Tiosol	1.0%	3 Apr	Tight cluster	Funguran-OH	0.1%
								10, 18, 27 Apr, 1, 8, 14, 23 May, 1, 10, 18, 25 Jun, 4, 14, 22, 29 Jul, 10 Aug	After tight cluster	Kumulus S	0.2%
											0.4%
2002				2002				2002			
25 Mar	Bud break	Cuproxat FW	0.1%	1 Apr	Bud break	Réxoxiklorid 50WP	0.3%	27 Mar	Green tip	Funguran-OH	0.1%
6 Apr	Green tip	Cuproxat FW	0.1%	15 Apr	Green tip	Réxoxiklorid 50WP	0.3%			Kumulus S	0.2%
15, 23 Apr, 3, 8, 18, 28, 31 May, 3, 13 Jun, 1, 8 Jul, 8, 15 Aug	After green tip	Szulfur 900FW	0.4%	23, 27 Apr, 5, 13, 20, 29 May, 2, 11, 14 Jun, 18 Jul	After green tip	Tiosol	1.0%	6 Apr	Tight cluster	Funguran-OH	0.1%
								15, 21, 29 Apr, 5, 14, 24, 31 May, 7, 15, 23, 30 Jun, 7, 16, 24, 31 Jul, 15 Aug	After tight cluster	Kumulus S	0.2%
											0.4%

^z Cuproxat FW: 350 g/liter copper sulfate, NuFarm Ltd., Linz, Austria; Szulfur 900FW: 900 g/liter elementary sulfur, Budapesti Vegyiművek GmbH, Budapest, Hungary; Réxoxiklorid 50WP: 50% copper oxychloride, Agroterm Ltd., Peremarton, Hungary; Réxkén 650FW: 200 g/liter copper oxychloride and 450 g/liter elementary sulfur, Nitrokémia 2000 GmbH, Füzfő, Hungary; Kumulus S: 80% elementary sulfur, BASF Hungaria Ltd., Budapest, Hungary; Tiosol: 29% calcium polysulfides, Tiosol Ltd., Kistelek, Hungary; Funguran-OH 50WP: 77% copper hydroxide, Spiess-Urania Chemicals GmbH, Hamburg, Germany.

chard floor covered by leaf litter at bud break (leaf litter density = LLD) was also determined in 2000, 2001, and 2002 (Table 2). Observations were carried out in 10 replicates by examining 200 randomly chosen leaves from the pruning treatment plots. For all years and all orchard sites, pseudothecial density (PD) and ascus density (AD) were based on 30.2 mature pseudothecia per visible lesion and 122.3 asci per pseudothecium, respectively (12). PAD was calculated as the average of 10 replicates for each year and orchard site.

Environmental monitoring. Leaf wetness duration (h), relative humidity (%), rainfall (mm), and temperature (°C) were detected at 12-min intervals using Metos Compact agrometeorological stations (Pessl Instrument GmbH, Weiz, Austria) in all orchards from mid-March until mid-October in 2000, 2001, and 2002 (Table 2). The agrometeorological stations were located at about 50, 40, and 30 m southwest of the experimental plots in the orchards at Nagykálló, Debrecen-Józsa, and Eperjeske, respectively, during each season. Sensors were mounted 1 m above the ground in the center of the canopy of a tree during each season at each site. Apple scab infection periods were calculated according to Mills and LaPlante (30) for each location and each year. In the experimental plots, a hygrothermograph (Techno Ltd., Budapest, Hungary) was mounted 1 m above the ground in the center of the canopy of a strongly pruned and an unpruned tree during each season at each site.

Spray deposition in pruned and unpruned trees. Fifteen apple trees (2.4 to 2.8 m tall and 1.3 to 1.7 m wide) were randomly assigned to five blocks of three trees each. In each block, the first tree was weakly pruned, the second strongly pruned, and the third not pruned. Pruning was performed in 2002 before bud break on 22, 24, and 26 February at Nagykálló, Debrecen-Józsa, and Eperjeske, respectively. The experiment was conducted on cv. Jonagold at Nagykálló and Debrecen-

Józsa and cv. Mutsu at Eperjeske. On 2 May (2 weeks after fruit set) and 3 July (full tree canopy size), 2002, 12 water-sensitive paper targets (3 × 8 cm) were systematically attached to twigs in each tree. Four targets were placed at each of three heights: lower (0.7 m from the ground), middle (1.5 m), and upper canopies (2.2 m). At each height, two targets were placed outside the canopy (within 10 cm of the edge of the canopy) and two targets were placed inside the canopy (within 10 cm of the tree trunk). Water was applied to the trees directly with a commercial airblast sprayer delivering 1,000 liters/ha and traveling at 5 km/h. Resulting spray deposition patterns on the papers were digitalized directly from the water-sensitive papers using a digital camera (Nikon Coolpix 4500, Nikon Corporation, Tokyo, Japan). Digitalized images were analyzed using image analysis software (Colim colour image measuring system, version 2.1, Pictron Ltd., Budapest, Hungary) on a personal computer.

Disease assessments. Disease assessments were made on leaves and fruits every 3 to 4 weeks from 1 April until 10 October in each year at each site. Observations were made on each tree of each treatment replicate. For leaf assessment, five 1-year-old woody lateral twigs were selected on each observed tree and at each assessment date. On each selected twig, disease was assessed on 50 leaves counted from the top of the shoot. For fruit assessment, 25 fruits typical for the given phenological stage were observed on each tree and at each assessment date. Leaves and fruits were considered to be diseased if at least one visible scab lesion was present on one leaf or fruit.

Leaf and fruit scab incidence were calculated as the percentage of leaves and fruits with at least one scab lesion, respectively. For each pruning treatment, the temporal dynamics of leaf and fruit scab epidemics were summarized in the area under the disease progress curve (AUDPC)

(2). AUDPC (percent-days) was calculated as:

$$\text{AUDPC} = \sum_{i=1}^{n-1} \left(\frac{y_i + y_{i+1}}{2} \right) \times (t_{i+1} - t_i)$$

where n is the total number of assessments, y_i is disease incidence at the i th assessment date, and the term $t_{i+1} - t_i$ is the time duration between two assessments.

Leaf and fruit scab severity as well as corresponding AUDPC were also calculated, but the significant differences between treatments for severity were similar to those for incidence; therefore, only incidence values were retained for analysis.

Statistical analyses. Disease assessment data from the three locations were analyzed separately. Calculated AUDPC values were divided into two data sets, one for leaf incidence and the other for fruit incidence. Both data sets were subjected to analysis of variance (ANOVA) using the Genstat 5 Release 4.1 statistical package (Lawes Agricultural Trust, IACR, Rothamsted, UK) in order to determine the effect of year, pruning, cultivar, and their interactions on AUDPC values. Then, for each cultivar and for each year, significant F tests ($P = 0.05$) were followed by a least significant difference (LSD) test for comparison of pruning treatment means using LSD_{0.05} values. Spray deposition data were analyzed by computing the water-darkened area as a percentage of a uniform area (25 × 40 mm) of each target. Means were separated using LSD_{0.05} values.

RESULTS

Potential ascospore dose. At each site, the mean lesion density (LD) ranged from 311 to 477 lesions per square meter of leaf at leaf fall, and the mean leaf litter density (LLD) was between 31.5 and 45.2% at bud break for the 3 years (Table 3). The mean production of ascospores per square meter of orchard floor (PAD) was 104,821 to 169,547 ascospores per square meter (Table 3), which shows that production of primary inoculum was high compared with

Table 3. Estimated potential ascospore dose (PAD) of *Venturia inaequalis* in organic apple orchards at Nagykálló, Debrecen-Józsa, and Eperjeske, Hungary (2000-2002)

Location and season	LD ^w		LLD ^x		PAD ^y	
	Estimate	SE ^z	Estimate	SE	Estimate	SE
Nagykálló						
2000	362	29.8	40.7	5.5	130,601	7,345
2001	467	44.3	37.4	6.4	154,822	8,467
2002	448	47.5	39.5	4.8	156,862	14,467
Debrecen-Józsa						
2000	335	36.2	35.3	6.2	104,821	9,345
2001	378	28.3	39.4	7.3	132,013	12,456
2002	411	49.2	31.5	7.1	114,757	8,234
Eperjeske						
2000	311	38.2	45.2	7.3	124,603	5,235
2001	422	40.1	43.2	10.2	163,891	14,325
2002	477	47.8	40.1	11.5	169,547	17,345

^w Lesion density: lesion number per square meter of leaf.

^x Leaf litter density: proportion of the orchard floor covered by leaf litter.

^y Potential ascospore dose: ascospore number per square meter of orchard floor.

^z Standard error.

an integrated orchard in all years and at all sites.

Environmental conditions. Environmental conditions for scab infection were variable among the three seasons and the three sites (Table 4). The number of infection periods from mid-March until mid-October ranged among sites from 15 to 17 in 2000, 22 to 25 in 2001, and 21 to 24 in 2002. Environmental conditions for scab infections were more favorable in 2001 and 2002 than in 2000 at all sites. There were no consistent differences in temperature or relative humidity within canopies of strongly pruned or unpruned trees (data not shown).

Spray deposition in pruned and unpruned trees. The percentage of area wetted by spray deposition did not increase significantly (7.3%; $P = 0.097$) on 2 May; however, the increase of deposition (23.1%) was significant ($P = 0.033$) on 3 July in strongly pruned trees compared with unpruned trees (Table 5). The major increase in deposition came in targets placed at 0.7 and 1.5 m (Table 5); however, there were no significant differences among target heights. The difference between the inner and outer canopies was not significant (data not shown).

Final disease incidence for leaf and fruit. For all years and all sites, means of final leaf incidence assessed at harvest time ranged from 36 to 66%, 24 to 40%, and 0 to 6% for susceptible, moderately susceptible, and resistant cultivars, respectively (Table 6). For all years and all sites, means of fruit incidence at harvest ranged from 18 to 30%, 4 to 13%, and 0 to 0.4% for susceptible, moderately susceptible, and resistant cultivars, respectively (Table 7).

AUDPC for leaf incidence. Epidemics of leaf scab, summarized in AUDPC, differed among cultivars, years, and pruning treatments (Table 6). Analysis of variance of AUDPC values (Table 8) indicated highly significant differences among the pruning treatments ($P < 0.001$ for Nagykálló and Debrecen-Józsa, $P < 0.01$ for Eperjeske) at each site. There were also highly significant differences among cultivars and among years ($P < 0.001$ for all sites). There were significant year $\times$ cultivar and cultivar $\times$ pruning interactions at all sites, but these were not as pronounced as the main effect of year or cultivar.

For all years and sites, means of AUDPC values for leaf incidence ranged from 1,734 to 4,692, 905 to 1,935, and 0 to 210 percent-days for the susceptible, mod-

erately susceptible, and resistant cultivars, respectively (Table 6). Pruning treatments significantly decreased development of leaf scab on the susceptible cultivars at all sites compared with that of unpruned treatments. For the susceptible cultivar Jonagold, AUDPC values of strongly pruned trees were significantly lower at $P = 0.05$ compared with either the weakly pruned or unpruned trees at Nagykálló and Debrecen-Józsa. However, the scab-susceptible cultivar Mutsu showed no significant differences between strongly and weakly pruned trees at Eperjeske in 2000, 2002, or in the mean of the 3 years. AUDPC values of the moderately susceptible cultivars were also significantly lower on strongly pruned trees compared with unpruned ones. However, the differences between the weakly pruned and the unpruned trees were variable depending on year and site. Pruning treatments showed no effect on leaf scab development for the V_f -resistant apple cultivars, except for the year 2001 at Nagykálló.

AUDPC for fruit incidence. Analysis of variance of AUDPC values for fruit incidence (Table 8) were similar to analysis of AUDPC values for leaf incidence and indicated significant differences among pruning treatments ($P < 0.05$), among the three cultivars ($P < 0.001$), and among the 3 years ($P < 0.001$). There was a significant year $\times$ cultivar interaction at all sites and a significant cultivar $\times$ pruning interaction at Debrecen-Józsa, but this was much smaller than the main effect of year or cultivar.

For all cultivars and all sites, means of AUDPC values were less for fruit incidence compared with leaf incidence; they ranged from 769 to 1,457, 132 to 514, and 0 to 19 percent-day for susceptible, moderately susceptible, and resistant cultivars, respectively (Table 7). The effect of pruning was smaller on development of fruit scab compared with that of leaf scab in all years and at all sites. Strong pruning treatments significantly decreased the means of AUDPC for fruit scab on susceptible cultivars compared with unpruned treatments in all sites. The effect of strong pruning treatments on moderately susceptible cultivars was significant only in 2001 at all sites. Resistant cultivars showed no significant effect of pruning treatments on development of fruit scab.

DISCUSSION

Pruning of apple trees enables management of tree shapes, increased growth of fruiting spurs, improved fruit coloration, and management of disease by the removal of diseased stems or dead wood that can harbor pathogens. The selective removal of branches also increases air movement within the tree canopy, which facilitates quicker drying of plant surfaces and a more uniform application of pesticides (3,27,41,42). Although, in this study, val-

Table 4. Number and severity of infection periods from mid-March until mid-October according to Mills and LaPlante (30) in organic apple orchards at Nagykálló, Debrecen-Józsa, and Eperjeske, Hungary (2000-2002)

Location and season	Severity of infection periods			Total
	Low	Moderate	Severe	
Nagykálló				
2000	6	8	3	17
2001	6	10	9	25
2002	8	7	8	23
Debrecen-Józsa				
2000	5	9	3	17
2001	4	13	8	25
2002	10	6	9	24
Eperjeske				
2000	5	7	3	15
2001	6	10	6	22
2002	9	7	4	21

Table 5. Percent coverage of spray deposition on paper targets placed in unpruned, weakly pruned, and strongly pruned apple trees in organic apple orchards (Nagykálló, Debrecen-Józsa, and Eperjeske, Hungary) on 2 May and 3 July 2002

	Target height (m)		
	0.7	1.5	2.2
2 May			
Unpruned	82 ^x a ^y	83 a	76 a
Weakly pruned	86 a	85 a	79 a
Strongly pruned	91 a	88 a	81 a
LSD _{0.05} ^z	10.5	8.9	11.8
3 July			
Unpruned	64 a	62 a	59 a
Weakly pruned	76 ab	79 ab	65 ab
Strongly pruned	83 b	81 b	74 b
LSD _{0.05}	17.9	18.2	15.4

^x Means of percent coverage of paper targets of the three orchards on unpruned, weakly pruned, and strongly pruned trees.

^y Values within columns and application date followed by different letters are significantly different.

^z Means in each pruning treatment were compared using least significance difference (LSD) test at $P = 0.05$.

ues of fruit and leaf scab incidence at harvest were high compared with a conventional or an integrated apple orchard (16,19,29), our data indicated that pruning generally reduced the incidence of scab in organic apple production (Tables 6 and 7). However, the impact of pruning on disease varied widely for leaf and fruit and was also influenced by cultivar susceptibility and location. Depending on year and loca-

tion, a susceptible cultivar showed greater effect of pruning on disease development than a moderately susceptible or a resistant cultivar. Moreover, the pruning treatments decreased the development of leaf scab more than that of fruit scab. Strong pruning significantly decreased the development of leaf scab on all susceptible and moderately susceptible cultivars at all sites and in almost all years, but the effect of

pruning on the development of fruit scab was consistent only on scab-susceptible cultivars.

In some previous studies, the effect of pruning on plant diseases has been related to the different microclimates of pruned and unpruned plants. Cooley et al. (4,5,7) indicated that the mode of action behind the decreased incidence of flyspeck in summer-pruned apple trees appeared to be

Table 6. Effect of pruning treatments on area under the disease progress curve (AUDPC) of leaf incidence for apple cultivars differing in susceptibility to apple scab in organic apple orchards at Nagykálló, Debrecen-Józsa, and Eperjeske, Hungary (2000-2002)

Year and cultivar ^t	Nagykálló				Debrecen-Józsa				Eperjeske			
	Unpr. ^u	Weak pr.	Strong pr.	LSD _{0.05} ^v	Unpr.	Weak pr.	Strong pr.	LSD _{0.05}	Unpr.	Weak pr.	Strong pr.	LSD _{0.05}
2000												
Susceptible	2550 (46) ^{wa}	2235 (44) b	2024 (41) c	195.1	2212 (43) a	1918 (39) b	1734 (36) c	184.3	2476 (44) a	2212 (42) b	2098 (42) b	189.4
Mod susc ^y	1112 (27) a	973 (24) b	905 (24) b	160.4	1312 (31) a	1245 (30) ab	1175 (29) b	154.2	1215 (29) a	1165 (29) ab	1098 (27) b	105.3
Resistant	135 (4) a	112 (4) a	109 (3) a	19.5	0 (0) ^z	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
2001												
Susceptible	4252 (62) a	3908 (58) b	3649 (55) c	239.5	3911 (59) a	3723 (57) b	3512 (54) c	240.7	4692 (66) a	4314 (62) b	4011 (60) c	276.5
Mod susc	1844 (38) a	1672 (35) b	1628 (36) b	133.2	1878 (38) a	1711 (36) b	1675 (36) b	160.5	1935 (40) a	1712 (37) b	1615 (36) b	195.7
Resistant	203 (6) a	172 (5) ab	170 (5) b	30.2	19 (0.5) a	32 (1) a	24 (1) a	20.2	0 (0)	0 (0)	0 (0)	0
2002												
Susceptible	3516 (54) a	3240 (52) b	2945 (50) c	183.7	3285 (52) a	3001 (50) b	2819 (48) c	181.3	3915 (59) a	3588 (55) b	3495 (55) b	190.7
Mod susc	1418 (32) a	1312 (30) b	1251 (30) b	112.8	1345 (31) a	1210 (30) ab	1157 (28) b	121.5	1432 (33) a	1305 (31) b	1242 (30) b	120.7
Resistant	210 (6) a	198 (6) a	185 (6) a	49.6	0 (0)	0 (0)	0 (0)	0	32 (2) a	24 (1) a	39 (2) a	19.2
Overall (2000-2002)												
Susceptible	3439 (54) a	3128 (51) b	2873 (49) c	204.5	3136 (51) a	2881 (48) b	2688 (46) c	202.4	3694 (56) a	3371 (53) b	3201 (52) b	219.1
Mod susc	1458 (32) a	1319 (30) b	1262 (30) b	136.8	1512 (33) a	1389 (32) ab	1336 (31) b	146.7	1527 (34) a	1394 (32) ab	1318 (31) b	140.9
Resistant	183 (5) a	161 (5) a	155 (5) a	33.2	6.3 (0.2) a	11 (0.3) a	8 (0.3) a	6.5	11 (0.7) a	8 (0.3) a	13 (0.7) a	6.3

^t Three cultivars differing in their susceptibility to apple scab were observed in all three orchards. Susceptible cultivars were Jonagold at Nagykálló and Debrecen-Józsa, and Mutsu at Eperjeske; moderately susceptible cultivars were Elstar at Nagykálló and Debrecen-Józsa, and Idared at Eperjeske; and resistant cultivars were Liberty at Nagykálló and Prima at Debrecen-Józsa and Eperjeske.

^u Unpr. = unpruned treatment; Weak pr. = weakly pruned treatment; and Strong pr. = strongly pruned treatment.

^v Means in each pruning treatment were compared using least significance difference (LSD) test at $P = 0.05$ for each cultivar and each site.

^w Values in bracket are means of final leaf incidence in percentage assessed at fruit harvest time.

^x Values within rows and locations followed by different letters are significantly different.

^y Moderately susceptible.

^z No scab symptoms were found in the treatment.

Table 7. Effect of pruning treatments on area under the disease progress curve (AUDPC) of fruit incidence for apple cultivars differing in susceptibility to apple scab in organic apple orchards at Nagykálló, Debrecen-Józsa, and Eperjeske, Hungary (2000-2002)

Year and cultivar ^t	Nagykálló				Debrecen-Józsa				Eperjeske			
	Unpr. ^u	Weak pr.	Strong pr.	LSD _{0.05} ^v	Unpr.	Weak pr.	Strong pr.	LSD _{0.05}	Unpr.	Weak pr.	Strong pr.	LSD _{0.05}
2000												
Susceptible	817 (20) ^{wa}	778 (19) a	769 (18) b	45.3	922 (22) a	858 (20) b	802 (20) b	62.1	1215 (28) a	1148 (28) ab	1135 (26) b	75.7
Mod susc ^y	152 (5) a	133 (4) a	140 (4) a	32.4	254 (7) a	232 (7) a	236 (6) a	35.2	165 (4) a	142 (4) a	148 (4) a	25.6
Resistant	0 (0) ^z	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
2001												
Susceptible	1355 (28) a	1323 (28) ab	1234 (27) b	110.1	1242 (28) a	1155 (27) b	1129 (26) b	80.4	1457 (30) a	1382 (30) ab	1342 (29) b	105.3
Mod susc	448 (12) a	422 (11) ab	400 (10) b	45.3	514 (13) a	485 (12) ab	457 (11) b	43.6	195 (6) a	167 (5) ab	161 (4) b	30.4
Resistant	11 (0.3) a	19 (0.4) a	14 (0.4) a	6.4	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
2002												
Susceptible	1188 (27) a	1117 (26) ab	1036 (24) b	132.7	914 (22) a	875 (20) ab	849 (20) b	55.1	912 (22) a	902 (21) ab	875 (20) b	34.3
Mod susc	402 (10) a	359 (9) a	358 (10) a	58.6	425 (11) a	399 (10) a	411 (9) a	42.5	151 (4) a	132 (4) a	139 (4) a	21.3
Resistant	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0
Overall (2000-2002)												
Susceptible	1118 (25) a	1073 (24) ab	1013 (23) b	102.6	1026 (24) a	963 (22) ab	927 (22) b	64.7	1195 (27) a	1144 (26) ab	1117 (25) b	71.9
Mod susc	334 (9) a	305 (8) a	299 (8) a	45.8	398 (10) a	372 (10) a	368 (9) a	40.6	170 (5) a	147 (4) a	149 (4) a	25.5
Resistant	5 (0.1) a	6 (0.1) a	5 (0.1) a	2.1	0 (0)	0 (0)	0 (0)	0	0 (0)	0 (0)	0 (0)	0

^t Three cultivars differing in their susceptibility to apple scab were observed in all three orchards. Susceptible cultivars were Jonagold at Nagykálló and Debrecen-Józsa, and Mutsu at Eperjeske; moderately susceptible cultivars were Elstar at Nagykálló and Debrecen-Józsa, and Idared at Eperjeske; and resistant cultivars were Liberty at Nagykálló and Prima at Debrecen-Józsa and Eperjeske.

^u Unpr. = unpruned treatment; Weak pr. = weakly pruned treatment; and Strong pr. = strongly pruned treatment.

^v Means in each pruning treatment were compared using least significance difference (LSD) test at $P = 0.05$ for each cultivar and each site.

^w Values in bracket are means of final fruit incidence in percentage assessed at fruit harvest time.

^x Values within rows and locations followed by different letters are significantly different.

^y Moderately susceptible.

^z No scab symptoms were found in the treatment.

related to the difference in the moisture content of air in the canopy. Gubler et al. (15), English et al. (11), and Houma et al. (22) demonstrated that Botrytis bunch rot of grape can be suppressed by the removal of leaves from around flower clusters. This reduction in disease was related to different microclimate parameters, with wind speed being the most important. However, for the most part, differences in disease incidence and severity have been difficult to explain based on measured differences in environmental factors such as temperature, relative humidity, or wetness duration. This study on apple showed that there were no consistent differences between temperature and relative humidity as monitored by hygrothermographs placed in the canopies of a strongly winter-pruned and an unpruned tree. In low-density apple orchards, Ocamb-Basu et al. (33) reported that sooty blotch severity of fruits at harvest averaged 9% less in winter-pruned trees than in unpruned ones. As in this study, they indicated that there were no consistent differences in temperature and relative humidity between pruned and unpruned trees. Savage and Sall (36) demonstrated that Botrytis fruit rot of grape was 47% greater on vines trained to a cross-arm style trellis than vines trained to a two-wire vertical trellis, respectively. However, only subtle differences in temperature or moisture regimes were associated with the change in trellis type or pruning treatments and change in disease incidence or severity. Moreover, it needs to be emphasized that RH and temperature are relatively conserved spatially in crop canopies; whereas the duration of leaf wetness (LWD) is far more variable spatially (13,28,40). In-canopy comparisons of LWD were not made among the pruning treatments in this study. In agreement with

Savage and Sall (36) and Ocamb-Basu et al. (33), we assume that pruning alters the microclimate of leaves or fruits by increasing air movement and light penetration, and in this way decreases the length of periods of wetness or high RH. These effects might also play a role in the reduction of apple scab development on leaves and fruits. Moreover, we assume that the reduction in disease observed may also be a result of more efficient fungicide deposition in pruned trees (Table 5). In agreement with our study, research in North Carolina found that spray deposition was greater and less variable on leaves in well-pruned trees than in unpruned ones (41,43,44). This is probably a result of more uniform penetration and distribution of sprayed material. Although fungicide deposition on fruit was not measured, it is reasonable to expect the same effect. Thus, improved spray penetration resulting from pruning is likely to supplement a possible micro-environmental difference in LWD, which may result in the reduction of leaf and fruit scab in dwarf trees in well-pruned organic apple orchards.

Differences in the effect of pruning on scab development of fruit and leaf in organic apple orchards may be due to the differences in their infection characteristics during the season. One- to four-day-old unfolded leaves are the most susceptible to the disease. With each passing day from this point, infection efficiency on leaves exponentially decreases with the ageing of the leaves (31,38). New leaves unfold from spring throughout the season; therefore, susceptible leaves are always present in the tree canopy, which allows for new infections if environmental conditions are favorable. However, fruits are the most susceptible until 2 to 4 weeks after fruit set; then a continuously increasing ontogenetic

resistance forms with the ageing of the fruits (39). Moreover, new fruits normally set only once a year; therefore, all fruits decrease in their susceptibility throughout the season. Until 2 to 4 weeks after fruit set, differences in spray deposition are only subtle between pruned and unpruned trees (Table 5), because leaf size is smaller and leaf number is lower than later in the season. Therefore, during the most susceptible phase of fruit development, circumstances for infection are similar in the pruned and unpruned trees. This may explain the finding that pruning had only a small effect on fruit scab epidemics (Table 7). However, the amount of foliar disease is greater on an unpruned tree than on a pruned one (Table 6) because young, susceptible leaves are present almost the entire season in the tree canopy. Furthermore, spray deposition on a pruned tree may be reduced and LWD increased in midseason, when leaves are fully unfolded, compared with early in the season, when leaves are small.

Today, sustainable fruit production is based on integrated and organic production guidelines. Growers are allowed to use synthetic fungicides in integrated fruit production. Thus, scab incidence can be held under a damage threshold level, even on a scab-susceptible apple cultivar (19,29). At the same three locations where the present study was made, the effect of winter pruning on apple scab was also investigated under a general integrated disease management practice on the same six apple cultivars. The results showed that the incidence of leaf and fruit scab was lower only on scab-susceptible cvs. Jonagold and Mutsu on strongly pruned trees compared with unpruned ones, although it was significant ($P = 0.05$) only in 2001 and 2002 (I. J. Holb, *unpublished*). The

Table 8. Analyses of variance (ANOVA) for effects of year, cultivar, and pruning on area under the disease progress curve (AUDPC) of leaf scab incidence and fruit scab incidence in organic apple orchards at Nagykálló, Debrecen-Józsa, and Eperjeske, Hungary over 2000-2002

Source of variation	df	Nagykálló		Debrecen-Józsa		Eperjeske	
		Mean square	F value ^z	Mean square	F value	Mean square	F value
Leaf							
Year	2	6,011,297	586.3 ***	5,279,112	695.1 ***	7,233,359	702.9 ***
Cultivar	2	81,144,521	7,914.7 ***	75,364,349	9,922.1 ***	105,456,219	10,288.5 ***
Pruning	2	634,204	61.5 ***	511,431	58.3 ***	505,615	49.1 **
Year × cultivar	4	1,979,554	193.1 ***	2,174,214	223.2 ***	3,688,517	358.4 ***
Year × pruning	4	2,489	0.3	37	0.0	22,683	2.2
Cultivar × pruning	4	228,688	22.3 **	155,218	20.4 *	190,834	18.5 **
Year × cultivar × pruning	8	968	0.1	3,048	0.4	8,370	0.8
Residual	81	10,250		7,595		10,291	
Total	107						
Fruit							
Year	2	694,487	419.1 ***	323,654	249.7 ***	282,286	216.8 ***
Cultivar	2	10,767,916	6,498.4 ***	8,635,702	6,662.7 ***	14,065,218	10,802.4 ***
Pruning	2	19,144	8.6 *	27,441	15.4 **	10,492	8.0 *
Year × cultivar	4	201,052	121.3 **	119,682	92.3 **	232,527	148.6 **
Year × pruning	4	2,324	1.4	732	0.6	990	0.7
Cultivar × pruning	4	7,070	3.7	8,070	6.9 *	5,004	3.8
Year × cultivar × pruning	8	1,014	0.6	566	0.4	562	0.4
Residual	81	1,657		1,296		1,296	
Total	107						

^z Values followed by *, **, and *** are statistically significant at $P < 0.05$, 0.01, and 0.001, respectively.

small effect of pruning on apple scab in the integrated orchards was probably due to the effectiveness of spray schedules and the low PAD values of the experimental plots. However, because fungicides are not as effective in organic apple production, other management practices might play an important role in disease management (10,17–19,29). In organic apple orchards, the risk of a scab epidemic is often high because the PAD is often high in spring (17–19). Value of PAD is dependent primarily on the amount of scab on leaves in autumn, and they are positively correlated with each other (12). Therefore, decrease of scab on leaves in autumn results in lower primary inoculum (PAD) in spring. This study showed that winter pruning, especially strong winter pruning, could reduce the amount of leaf scab until harvest and resulted in lower AUDPC on pruned trees than on unpruned ones (Table 8). Consequently, PAD might be lower in spring in a well-pruned apple orchard than in a weakly pruned or an unpruned one. Moreover, Holb et al. (20,21) demonstrated that scab conidia could overwinter inside buds in most organic orchards and cause early scab epidemics before the period of ascospore infection; and it was also shown that these overwintered conidia could be effectively reduced by pruning of the upper third part of the last year's extension shoots before bud break. The authors noted that this winter pruning could be crucial in organic apple orchards where scab incidence in autumn is above 40%, because the effect of usual fungicide applications at bud break might be partial, as most of the fungicides used in organic orchards are "contact", and consequently, it might be difficult to reach conidia inside buds and prevent infection. Therefore, pruning of apple trees as a management tactic for control of apple scab might act via three possible mechanisms: removal of overwintered conidia inside buds, improvement of spray penetration, or modification of in-canopy microclimate. However, more research is needed to determine which mechanism is the key one in disease reduction by winter tree pruning in organic apple orchards.

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