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Effect of six sanitation treatments on leaf litter density, ascospore production of *Venturia inaequalis* and scab incidence in integrated and organic apple orchards

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Abstract

A two-year study was conducted to determine the effect of six sanitation treatments on leaf litter density (LLD), relative ascospore production of *Venturia inaequalis* and scab incidence on spur-leaf clusters, leaves and harvested fruits, on two cultivars with low and high scab susceptibilities, in Hungarian integrated and organic apple orchards. The following sanitation treatments were used: sprays of lime sulphur in autumn, collecting fallen leaves in autumn, straw mulch cover in late winter, sprays of lime sulphur followed by mulch cover, collecting fallen leaves followed by mulch cover, collecting fallen leaves followed by covering the orchard floor with plastic foil, and non-sanitized control. LLD decreased continuously in all treatment plots by 0–23% by mid-May in both orchards and years; however, LLD reduction was 1.4–4.2 times higher in the organic orchard compared to the integrated one. All treatments, except for the lime sulphur treatment, resulted in significant ($P < 0.05$) reduction of LLD and ascospore production in both the integrated and organic apple orchards compared to non-sanitized plots. The most efficient treatment was leaf collection combined with plastic foil cover, followed by leaf collection combined with mulch cover, leaf collection alone, mulch cover alone, and lime sulphur spray combined with mulch cover, with a reduction in the ascospore production of >95, 72–92, 56–79, 24–38, and 27–46%, respectively, in the mean of both orchards and years. However, only treatments of leaf collection applied alone, or in combination with mulch or with plastic foil cover reduced significantly ($P < 0.05$) leaf and/or fruit scab incidence by 18–57% compared to non-sanitized plots. These three leaf collection treatments are recommended in both integrated and organic orchards and the possibilities of successfully incorporating these methods into orchard management practices are interpreted.

Introduction

Apple scab, caused by *Venturia inaequalis*, is the most prevalent polycyclic disease of apples in temperate zones of the Earth. In most apple growing areas, crop losses due to apple scab would be about 50–90% if appropriate control measures were not applied; therefore, several fungicide applications are used to suppress disease development in both integrated and organic apple production (MacHardy, 1996). In integrated apple orchards, scab management typically involves 6–16 fungicide treatments per season, depending on weather conditions and the amount of inoculum (Beresford and Manktelow, 1994; MacHardy, 1996; Holb et al., 2003b). According to international organic growing guidelines, only a few approved fungicidal products are available for apple scab control, such as sulphur and copper compounds (Anon., 1989). These compounds are often less effective and more phytotoxic than modern synthetic fungicides used in integrated fruit growing; therefore, in organic apple orchards, 10–26 sprays are applied against apple scab in each season, depending primarily on cultivar susceptibility, weather conditions and the amount of inoculum (Ellis et al., 1998; Holb et al., 2003a).

As environmental considerations have become more important in crop protection, considerable research has been done to reduce the use of pesticides (Sutton, 1996). In both integrated and organic apple orchards, one of the most environmentally safe methods of reducing fungicide applications against apple scab is to apply sanitation treatments in the previous autumn and/or the following early spring (MacHardy and Jeger, 1983; MacHardy, 1996). Various strategies for the use of non-chemical sanitation practices against apple scab have been evaluated, such as burning or ploughing (Curtis, 1924), applying urea to leaf litter and the shredding of leaf litter (e.g. Sutton et al., 2000; Vincent et al., 2004), covering the orchard floor with plastic (Holb et al., 2004a, b) and the use of fungal antagonists (e.g. Heye and Andrews, 1983; Carisse et al., 2000; Vincent et al., 2004) to suppress the ascigerous stage of *V. inaequalis*. In general, the above sanitation practices either suppressed the pseudothecial development and/or limited the discharge of *V. inaequalis* ascospores and/or reduced the risk of scab infection in small-scale studies. There were reductions of 40–95% and 45–85% in ascosporic inoculum and in scab incidence the following spring, respectively. Sutton et al. (2000) concluded that the reduction of early spring scab-risk by orchard sanitation is estimated to be 50–80% in integrated orchards. Based on this finding, Sutton et al. (2000) developed sanitation treatments by urea and leaf shredding applied to fallen leaves using the scab-risk action threshold in early spring (MacHardy et al., 1993), but little attention has been paid to evaluating the scab-risk reduction potential of other sanitation treatments, such as lime sulphur sprays, mulch cover or leaf collection.

A previous study showed that foliar application of lime sulphur significantly reduced scab incidence during the season (Holb et al., 2003a); however, the scab reduction potential of lime sulphur on infected fallen leaves has not been investigated. Several studies revealed that mulch cover increased the biological activity of soils (e.g. Niklas et al., 1979; Haynes, 1981), which enhanced leaf degradation (Haynes, 1981; Paoletti et al., 1998), and therefore it can be hypothesized that mulch cover is likely to reduce the primary scab inoculum source on fallen infected leaves. Leaf collection has a direct reduction effect on all pathogens and pests, which overwinter on fallen leaves (Heitefuss, 1989); therefore, a significant reduction in scab-risk potential of primary infections can be expected. However, no scientific attention has been paid to evaluating the above orchard sanitation options and their combinations in moderately infested (such as integrated) and/or in severely infested (such as organic) apple orchards on apple cultivars with different scab susceptibility. If the above mentioned sanitation options reduce scab-risk in integrated apple orchards, then they may also suppress primary scab development and epidemics in organic orchards and, in this way, partially counterbalance the low fungicide efficacy against apple scab during the first part of the ascosporic infection period.

The objectives of this study were to evaluate the effectiveness of sanitation treatments of lime sulphur sprays, mulch cover, leaf collection and plastic foil cover on leaf litter density, ascospore production of *V. inaequalis* and scab incidence in spring in high-density integrated and organic apple orchards. Cultivars with different susceptibility to scab were evaluated and possible incorporations of the most effective sanitation treatments into the orchard management practices are discussed according to their scab reduction potential.

Materials and methods

Orchards and plant materials

The study was carried out in an integrated apple orchard and in an organic apple orchard in 2003 and 2004. The integrated orchard was located at 47°31′60″ N and 21°37′60″ E, in Nagykálló, Eastern Hungary. The organic orchard was in Eperjeske, 89 km north of the orchard at Nagykálló.

In Nagykálló, the 10 ha orchard consisted of 44 rows, with a distance between rows of 4 m and within a row of 1.5 m. The orchard consisted of seven apple cultivars in a random row arrangement, with a minimum of 1500 trees i.e. approximately four rows of each cultivar. Trees were on M.26 rootstocks, pruned to spindle shape and planted in 1996. Trees were grown according to the Hungarian IFP (Integrated Fruit Production) guidelines derived from international IFP standards (Cross and Dickler, 1994). Observations were made on a scab susceptible (cv. Jonagold) and on a moderately susceptible apple cultivar (cv. Elstar).

The 15 ha organic orchard (Eperjeske) was planted in 1997. It consisted of eight apple cultivars in a random row arrangement, with a minimum of 1500 trees i.e. at least four rows of each cultivar. All trees were on M.26 rootstocks and pruned to a spindle shape. Trees were placed with a between-row spacing of 5 m, and a within-row spacing of 2 m. Observations were made on a scab susceptible (cv. Jonagold) and on a moderately susceptible apple cultivar (cv. Jonathan). Trees were grown according to the Hungarian Organic Guidelines derived from international IFOAM (International Federation of Organic Agriculture Movements) standards (Anon., 1989).

In both locations, grass alleys were maintained within and between rows and drip irrigation was applied during dry periods in 2003.

Climatic monitoring

Potential infection periods, based on the criteria of Mills and La Plante (1951), were recorded at each location with a METOS agrometeorological station (Pessl Instrument GmbH, Weiz, Austria) from 10 March until 15 October, in 2003 and 2004. During the same periods, wind speed and wind direction were recorded with an A100R switching anemometer (Campbell Scientific Ltd., Shepshed, Loughborough, England). In order to show year and location differences of weather variables, precipitation (mm day^{-1}), and temperature (°C day^{-1}) were also detected with the same agrometeorological stations throughout the period of October 2002 to October 2004, in both locations.

Potential ascospore dose

In spring, the potential ascospore dose (PAD), was calculated in the non-sanitized plots of both orchards and cultivars according to Gadoury and MacHardy (1986), in order to demonstrate differences in the inoculum sources between orchards and cultivars. The mean number of scab lesions leaf m^{-2} at leaf fall (lesion density = LD) was recorded on 16 October 2002 and 5 November 2003. The proportion of the orchard floor covered by leaf litter at bud break (leaf litter density = LLD) was also determined on 21 March 2003 and 27 February 2004. Observations were carried out in 10 replicates by examining 200 randomly chosen leaves from the non-sanitized treatment plots. For both years and both orchard sites, pseudothecial density (PD) and ascal density (AD) were based on 30.2 mature pseudothecia per visible lesion and 122.3 asci per pseudothecium, respectively. PAD was calculated as the average of 10 replicates for each year, orchard site and cultivar.

Sanitation treatments

In both locations, seven treatments in four replicates were prepared in a completely randomized block design in the autumn of 2002 and 2003. The size of the experimental unit (one replicate of each treatment) was 40×37.5 m in Nagykálló and 50×50 m in Eperjeske, including 250 trees per unit in both locations. Experimental units were rearranged in the second year. Treatments were as follows: (1) spray applications to leaves on the tree and then on the orchard floor with lime sulphur in autumn, Lime-S; (2) collection of fallen leaves in autumn; Collect-L; (3) mulching the orchard floor in late winter, Mulch-C; (4) two autumn sprays of lime sulphur (treatment 1), followed by mulching the orchard floor (treatment 3), Lime-S + Mulch-C; (5) collection of fallen leaves (treatment 2), followed by mulching the orchard floor (treatment 3), Collect-L + Mulch-C; (6) collection of fallen leaves (treatment 2), followed by covering the orchard floor with plastic foil, Collect-L + Plastic-F; (7) Non-sanitized control.

In treatments 1 and 4 of both locations, leaves on the trees were treated with 2% Tiosol (29% calcium polysulphide, Tiosol Ltd., Kistelek, Hungary) before leaf fall in October 2002 and 2003

(Table 1). An additional 4% Tiosol spray was applied to the fallen leaves in November 2002 and 2003 (Table 1). Sprays were applied with a Kertitox 2000 axial blower spray machine (Debreceni Gépgyár B.V., Debrecen, Hungary) in both years. In treatments 2, 5 and 6 of both locations, leaves were collected with a John Deere F-725 flail mower (Deere & Company, Moline, Illinois, USA) after defoliation in November 2002 and 2003 (Table 1). In treatments 3, 4 and 5 of both locations, the full experimental area was covered with a 10 cm mulch-layer of winter wheat straw after the lime sulphur or the leaf collecting treatment in treatments 4 or 5, respectively, before bud break. However, the mulching treatment was not performed in autumn, but only in February 2003 and 2004 (Table 1), in order to reduce the favourable habitat for the swarming of voles during late autumn and winter. In treatment 6 of both locations, the soil was completely covered by colourless polythene sheet (thickness 0.05 mm) also in February 2003 and 2004, before bud break (Table 1). The polythene sheet was fixed to the ground with wire pins to prevent removal by wind and to exclude the ascosporic inoculum source from the experimental unit. The polythene sheet was removed from the ground at the end of May after the last day of the ascopore production assessment in each year (Table 1). The use of polythene sheet reduced weed emergence and advanced tree development in treatment 6, which was about 7–10 days ahead compared to other plots by the end of May due to the increased temperature under polythene sheet.

Each experimental unit of both the integrated and organic orchards received a general spray schedule against apple scab during the two seasons (Table 2). In the integrated orchard at Nagykálló, an approved integrated spray programme was applied according to the Hungarian IFP guidelines derived from European IFP guidelines (Cross and Dickler, 1994) (Table 2). In the organic orchard at Eperjeske, an approved organic spray programme was applied during the whole season according to the organic guidelines derived from IFOAM guidelines (Anon., 1989) (Table 2). In both orchards, all sprays were applied with a Kertitox 2000 axial blower spray machine (Debreceni Gépgyár B.V., Debrecen, Hungary) with a ceramic hollow cone at 1.1–1.2 MPa with a volume of 1000 l ha^{-1}.

Assessments of LLD

A point-intercept method (Gadoury and MacHardy, 1986) was used to determine LLD in all sanitized treatments of both the integrated and organic orchards. For eight trees randomly selected from each experimental unit, eight transects were made on diagonals across the adjacent rows. Using

Table 1. Dates of assessments and management activities in an integrated apple orchard at Nagykálló and in an organic apple orchard at Eperjeske in Hungary (2002–2004)

Activities	Integrated orchard		Organic orchard	
	2002/2003	2003/2004	2002/2003	2003/2004
Lime sulphur sprayed to				
tree (dosage 2%)	19 October 2002	20 October 2003	18 October 2002	17 October 2003
orchard floor (dosage 4%)	4 November 2002	25 November 2003	1 November 2002	21 November 2003
Leaf collection	6 November 2002	26 November 2003	2 November 2002	23 November 2003
Mulching	22 February 2003	9 February 2004	20 February 2003	3 February 2004
Placement of polythene sheet	24 February 2003	10 February 2004	22 February 2003	6 February 2004
LLD assessment				
1st assessment	12 December 2002	16 December 2003	10 December 2002	18 December 2003
2nd assessment	21 March 2003	17 March 2004	16 March 2003	10 March 2004
3rd assessment	10 May 2003	5 May 2004	2 May 2003	1 May 2004
Assessment of ascospore production				
from	22 March 2003	5 March 2004	14 March 2003	1 March 2004
to	31 May 2003	24 May 2004	30 May 2003	22 May 2004
Scab assessment				
spur-leaf cluster	27 May 2003	23 May 2004	25 May 2003	22 May 2004
leaf	22 June 2003	25 June 2004	24 June 2003	27 June 2004
harvested fruit	5 October 2003	3 October 2004	7 October 2003	2 October 2004

Table 2. Spraying schedules against apple scab in an integrated apple orchard at Nagykálló and in an organic apple orchard at Eperjeske in Hungary (2003 and 2004)

2003				2004			
Date	Phenological stage	Active ingredients, Trade name[a]	Dosage (%)	Date	Phenological stage	Active ingredients, Trade name[a]	Dosage (%)
Integrated orchard (Nagykálló)				*Integrated orchard (Nagykálló)*			
02 April	Early tight cluster	copper sulphate, Cuproxat FW	0.2	5, 12 April	Early tight cluster	difenoconazole, Score 250 EC	0.05
14 April	Tight cluster	difenoconazole, Score 250 EC	0.05	17 April	Tight cluster	pyrimethanil, Mythos 30 EC	0.15
21 April	Tight cluster	pyrimethanil, Mythos 30 EC	0.15	25 April	Blooming	difenoconazole, Score 250 EC	0.05
27 April	Blooming	difenoconazole, Score 250 EC	0.05	2 May	Petal fall	pyrimethanil, Mythos 30 EC	0.05
4 May	Petal fall	difenoconazole, Score 250 EC	0.05	7 May	Petal fall	kresoxim-methyl, Discus DF	0.02
9 May	Petal fall	trifloxistrobin, Zato 50 WG	0.02	10 May	Fruit setting	pyrimethanil, Mythos 30 EC	0.15
12 May	Fruit setting	pyrimethanil, Mythos 30 EC	0.15	16, 22 May	Fruit swelling	trifloxistrobin, Zato 50 WG	0.02
26 May, 27 June	Fruit swelling	kresoxim-methyl, Discus DF	0.02	1, 9 June,	Fruit swelling	difenoconazole, Score 250 EC	0.05
1, 11 June,	Fruit swelling	difenoconazole, Score 250 EC	0.05			captan, Captan 50 WP	0.15
		dithianon, Delan 700 WG	0.15	15 June, 20, 27 July	Fruit swelling	difenoconazole, Score 250 EC	0.05
16 June, 21 July	Fruit swelling	difenoconazole, Score 250 EC	0.05	4, 27 July		dithianon, Delan 700 WG	0.05
7 July		captan, Captan 50 WP	0.05	15 July, 4, 12 Aug		dodine, Efuzin 500 FW	0.09
				25 Aug, 5 Sept		captan, Captan 50 WP	0.05
Organic orchard (Eperjeske)				*Organic orchard (Eperjeske)*			
28 March	Bud swelling	elementary sulphur, Kumulus S	0.2	18 March	Bud swelling	elementary sulphur, Kumulus S	0.2
		copper hydroxide, Funguran-OH	0.1			calcium polysulphide, Tiosol	2.0
7 April	Green tip	elementary sulphur, Kumulus S	0.2	31 March	Green tip	elementary sulphur, Kumulus S	0.2
		copper hydroxide, Funguran-OH	0.1			copper hydroxide, Funguran-OH	0.1
15, 21, 29 April, 5, 14, 24, 31 May, 7, 15, 23, 30 June, 7, 16, 24, 31 July, 15 Aug.	After green tip	elementary sulphur, Kumulus S	0.4	5, 12, 18, 26 April, 4, 12, 21, 29 May, 3, 19, 25, 30 June, 8, July, 3, 12, 30 Aug., 5 Sept.	After green tip	elementary sulphur, Kumulus S	0.4
				11, June, 14, 29 July 23 Aug.	Fruit swelling	calcium polysulphide, Tiosol	1.0

[a]Cuproxat FW: 350 g l^{-1} copper sulphate, NuFarm Ltd., Linz, Austria; Kumulus S: 80% elementary sulphur, BASF Hungaria Ltd., Budapest, Hungary; Tiosol: 29% calcium polysulphide, Tiosol Ltd., Kistelek, Hungary; Funguran-OH 50 WP: 77% copper hydroxide, Spiess-Urania Chemicals GmbH, Hamburg, Germany; Score 250 EC: 250 g l^{-1} difenoconazole, Syngenta Ltd., Budapest, Hungary; Mythos 30 EC: 300 g l^{-1} pyrimethanil, Aventis Crop Science Ltd., Budapest, Hungary; Zato 50 WG: 50% trifloxistrobin, Bayer Hungaria Ltd., Budapest, Hungary; Discus DF: 50% kresoxim-methyl, BASF Hungaria Ltd., Budapest, Hungary; Delan 700 WG: 70% dithianon, BASF Hungaria Ltd., Budapest, Hungary; Captan 50 WP: 50% captan, Bayer Hungaria Ltd., Budapest, Hungary; Efuzin 500 FW: 500 g l^{-1} dodine, Agrokémia Sellye GmbH, Sellye, Hungary.

a measuring tape along each transect, the presence of leaves under the tape was observed at 25 cm intervals; if a leaf was present, then it was denoted as 1, 0, otherwise. The LLD was calculated as the proportion of the points under which leaves were found. Assessment of LLD was made in December, March and May in both years and locations (Table 1).

Assessments of ascospore production

Total ascospore production was evaluated during the ascospore ejection period at both locations in each treatment (Table 1). An enclosed shelter spore-trap (Figure 1) was developed to collect ascospores discharged from a 150 cm^2 sampling area within each experimental unit of the treatments. The spore collecting area of the trap was a 15 × 10 cm rectangle framed with wood. A wire-mesh screen stretched over the wooden frame prevented leaves from moving into, or out of, the sampling area; 0.5 cm above the wire-mesh, a console for eight 25 × 75 mm glass microscope slides was structured. The height of the trap was 8 cm and the shelter was covered on the top with an openable Plexiglas side panel to allow light to enter the shelter and the change of microscope slides. The spore trap was fixed to the soil with four iron pins in the corners of the trap in the middle of a unit of each treatment. To estimate the amount of ascospores, eight 25 × 75 mm glass microscope slides coated with a thin layer of vaseline were placed on the eight consoles for the slides (Carisse et al., 2000). The slides were facing downwards and collected twice a week and replaced with new ones. Collected slides were stored at 8 °C until examination. The number of ascospores was counted on 40% of the trapping surface of each slide under a microscope at a magnification of × 250. The total ascospores collected were estimated for each slide as $Y = 2.5 \times X$ where Y is the estimated total number of ascospores per slide and X is the number of ascospores counted. Countings of the eight slides per trap were averaged for each sampling date; for each treatment, percent reduction of trapped ascospores was calculated and reported for each year, location and cultivar. Percent reduction of trapped ascospores ($R\%$) was estimated as

$$R\% = \frac{\text{NST} - \text{ST}}{\text{NST}} \times 100$$

where ST is the total number of ascospores collected from a sanitized treatment, and NST is

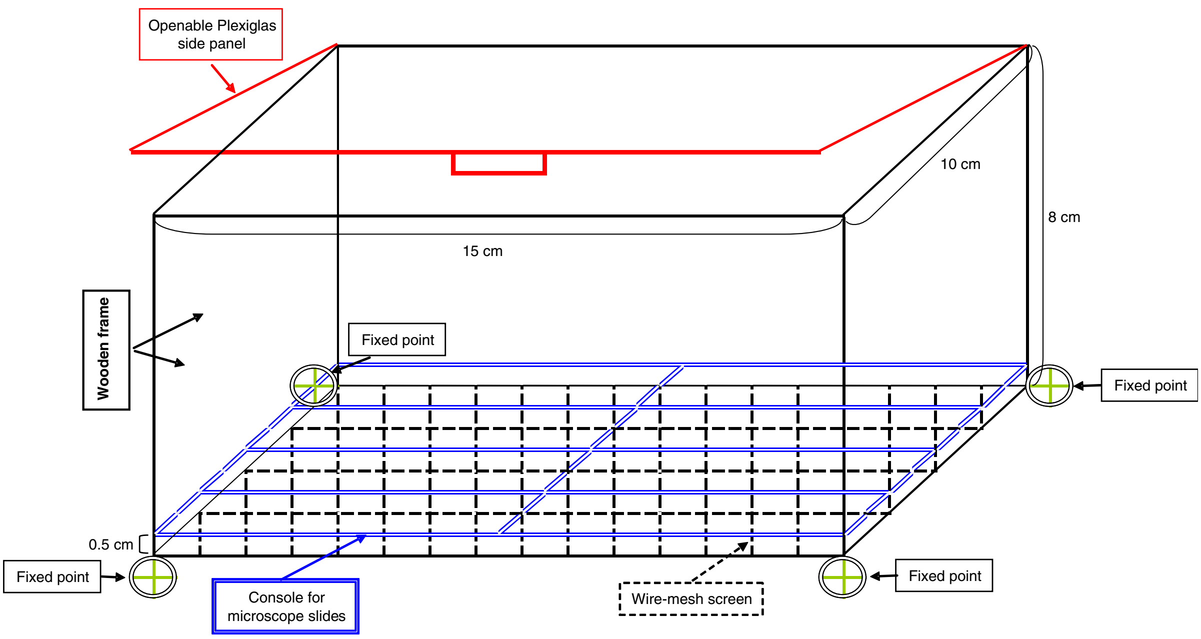

Figure 1. Enclosed shelter spore-trap used for assessing ascospore production of *V. inaequalis* in the sanitation treatments.

the total number of ascospores collected from a corresponding non-sanitized treatment. Spore traps were continuously operated from March until end-May in both years and locations (Table 1).

Disease assessments

In both locations, scab assessments were made on leaves and fruits in both years. Disease assessments were done in the middle 10 trees of each experimental unit in order to reduce the neighbouring effect of other plots. For leaf assessment, 20 fruiting spur-leaf clusters per tree were assessed at the end of May in each year (Table 1). In each spur-leaf cluster, all leaves were assessed for scab symptoms. Leaf scab was also recorded on 10 extension shoots per tree at the end of June in each year (Table 1). Assessments were made on the 10 oldest leaves per shoot at the base of the shoot; the percentage of diseased fruits was also assessed on all fruits of the 10 assessed trees of each experimental unit at harvest in each year (Table 1). Scab incidence of spur-leaf clusters, leaves and fruits was calculated as the percentage of spur-leaf clusters, leaves and fruits diseased, respectively. Leaf and fruit scab severities were also calculated but severity values of spur-leaf clusters were very low and the significant differences between treatments for severity of leaves and fruits were similar to those for incidence; therefore, only incidence values were retained for analysis.

Statistical analyses

Percent LLD, percent reduction of trapped ascospores and disease incidence data were transformed to *angular* (Y = arcsine $[\%]^{1/2}$) to correct normality before analysis. Analysis of variance (ANOVA) was used to evaluate the effects of year, cultivar, sanitation, and their interactions on LLD, percent reduction of trapped ascospores and scab incidence. For all data sets, significant F-tests ($P < 0.05$) were followed by a Least Significance Difference (LSD)-test for comparing treatment means using SED (standard errors of difference) values. Significant differences of minimum and maximum daily temperatures of each dormant period (from 1 November to February 27), and significant differences of scab incidence between cultivars and between years were also tested by F-tests ($P < 0.05$). Genstat 5 Release 4.1 statistical package (Lawes Agricultural Trust, IACR, Rothamsted, UK) was used for all analyses.

Results

Climatic conditions

Climatic conditions were similar in both locations; however, the amplitudes of temperature and precipitation were slightly larger at Eperjeske, compared to those at Nagykálló. The number of infection periods was 19 and 37 at Nagykálló, and 20 and 35 at Eperjeske, in 2003 and 2004, respectively, from mid-March until mid-October. During the growing seasons, monthly mean temperature ranged from 3.9 to 22.1 °C and from 5.3 to 20.8 °C at Nagykálló, and from 3.4 to 22.3 °C and from 5.0 to 20.3 °C at Eperjeske, in 2003 and 2004, respectively, from 1 March to 31 October. During the tree dormant periods, monthly mean temperature ranged from −5.4 to 3.1 °C and from −2.1 to 6.1 °C at Nagykálló, and from −5.9 to 3.0 °C and from −2.5 to 5.4 °C at Eperjeske in 2002/2003 and 2003/2004, respectively, from 1 November to February 28. During the tree dormant periods of 2003/2004, the minimum daily temperature was significantly higher (P = 0.047), while the maximum daily temperature was not (P = 0.236), compared to that of 2002/2003 (data not shown). The amounts of precipitation during the growing seasons were 297.2 and 545.5 mm at Nagykálló, and 281.8 and 526.6 mm at Eperjeske in 2003 and 2004, respectively, and during the tree dormant periods, 49.3 and 124.6 mm at Nagykálló, and 73.4 and 130.8 mm at Eperjeske in 2002/2003 and 2003/2004, respectively. In Eperjeske, the wind direction was north, east, south and west for 23%, 28%, 21% and 15% in 2003; 31%, 15%, 16%, and 22% in 2004, respectively, and in Nagykálló north, east, south and west for 31%, 23%, 11% and 12% in 2003; 25%, 29%, 9% and 20% in 2004, respectively, during the time from 10 March to 15 October. During the same period, wind velocity ranged from 2 to 6 m s^{-1} for 77, and 71 in Eperjeske and 72% and 67% in Nagykálló in the 2 years, respectively.

Potential ascospore dose

In the non-sanitized plots of the integrated orchard, mean production of ascospores m^{-2} orchard floor (PAD) was 2,827 (SE = 211) in 2003 and 3549 (SE = 342) in 2004 on cv. Jonagold, and 923 (SE = 44) in 2003 and 1154 (SE = 109) in 2004 on cv. Elstar (Table 4). The mean PAD was 142,745 (SE = 12,173) in 2003 and 164,047 (SE = 22,664) in 2004 on cv. Jonagold, and 73,457 (SE = 6,542) in 2003 and 94,598 (SE = 10,672) in 2004 on cv. Jonathan in the non-sanitized plots of the organic orchard.

LLD

In both orchards, analyses of variance on LLD values indicated significant differences ($P < 0.05$) between years and sanitation treatments but no significant effect was found for the cultivars (Table 3). Therefore, LLD data were averaged for the two cultivars and not shown separately for both orchards and years (Table 4). In both orchards, LLD decreased continuously by 0–23% in all treatment plots from early-December to mid-May the following spring in both years; however, LLD reduction of the treatments by mid-May was 1.4–4.2 times higher in the organic orchard compared to the integrated one (Table 4). In both orchards, total LLD elimination was achieved in the treatment of leaf collection combined with plastic foil cover (Collect-L + Plastic-F). All other leaf-collecting treatments (Collect-L and Collect-L + Mulch-C) significantly ($P < 0.05$) reduced LLD compared to non-sanitized plots in all assessment dates and both orchards. Treatments of mulching orchard floor (Mulch-C and Lime-S + Mulch-C) resulted in lower LLD reduction than the leaf collecting treatments but they were still significantly different ($P < 0.05$) from the non-sanitized plots. In both years, sprays of lime sulphur (Lime-S) did not reduce LLD significantly ($P < 0.05$)

Table 3. Analysis of variance describing the effect of year, cultivar, and sanitation treatments on LLD, percent ascospore reduction, scab incidences of spur-leaves, leaves, and harvested fruits in an integrated apple orchard at Nagykálló and in an organic apple orchard at Eperjeske in Hungary (2003 and 2004)

Source of variation	df[b]	LLD[a]		Ascospore reduction (%)		Spur-leaf cultivar scab		Leaf scab		Fruit scab	
		MS[c]	$P > F$[d]	MS	$P > F$	MS	$P > F$	MS	$P > F$	MS	$P > F$
Integrated orchard											
Year (Y)	1	2010.6	0.049	67.1	0.048	41.7	< 0.001	326.4	< 0.001	555.8	< 0.001
Cultivar (C)	1	4.9	0.934	752.0	< 0.001	21.8	< 0.001	75.2	< 0.001	92.3	0.004
Sanitation (S)	6	8040.2	< 0.001	6,558.4	< 0.001	7.8	< 0.001	15.9	0.035	23.2	0.048
Y × C	1	45.1	0.956	32.1	0.155	0.7	0.332	14.4	0.054	15.8	0.225
Y × S	6	255.5	0.480	4.9	0.634	0.6	0.512	7.0	0.138	6.8	0.698
C × S	6	7.5	0.992	59.9	0.046	0.5	0.658	5.1	0.299	22.8	0.057
Y × C × S	6	40.8	0.967	2.8	0.756	0.5	0.670	6.0	0.209	6.1	0.749
Residual	84	695.5		5.6		0.7		4.1		10.6	
Total	111										
Organic orchard											
Year (Y)	1	1188.5	0.047	63.2	0.043	35.1	< 0.001	2910.1	< 0.001	3284.3	< 0.001
Cultivar (C)	1	8.9	0.906	868.5	< 0.001	74.7	< 0.001	2912.1	< 0.001	7099.4	< 0.001
Sanitation (S)	6	5174.6	< 0.001	5944.6	< 0.001	11.7	< 0.001	36.9	0.044	98.3	0.049
Y × C	1	44.3	0.955	6.5	0.442	0.1	0.923	97.8	0.036	300.1	0.021
Y × S	6	183.9	0.497	35.8	0.127	2.6	0.155	10.5	0.689	28.3	0.702
C × S	6	4.6	0.995	6.1	0.433	1.3	0.541	3.7	0.965	22.3	0.806
Y × C × S	6	32.8	0.977	1.1	0.812	0.4	0.916	13.2	0.558	52.6	0.325
Residual	84	641.8		4.4		1.6		16.2		44.6	
Total	111										

[a]Assessment dates were pooled over for data of LLD in the analyses.
[b]df = degree of freedom.
[c]MS = Mean squares.
[d]The probability values associated with the *F*-tests.

compared to non-sanitized plots in either the integrated or the organic orchards (Table 4).

Percent reduction of trapped ascospores

In both orchards, analyses of variance on percent ascospore reduction (Table 3) indicated significant differences ($P < 0.05$) between years, cultivars and sanitation treatments. There was a significant cultivar × sanitation treatment interaction in the integrated orchard but this was not as dominating as the main effect of year or cultivar or sanitation treatment (Table 3).

In both the integrated and organic orchards, all sanitation treatments significantly ($P < 0.05$) reduced the total number of ascospores compared to non-sanitized plots, except for the spray of lime sulphur (Table 5). In both orchards, the highest reduction in ascospore production was obtained for the treatment of leaf collection combined with plastic foil cover (Collect-L + Plastic-F), with >95% reduction in ascospore production. Other leaf collection treatments, Collect-L + Mulch-C and Collect-L, significantly ($P < 0.05$) reduced ascospore production by 87–92% and 56–79% in the integrated and by 72–79% and 61–65% in the organic orchards, respectively. The other mulching treatments, Mulch-C and Lime-S + Mulch-C, were the least efficient (but still significant at $P < 0.05$) sanitation treatments, with a reduction in ascospore production of 31–38 and 40–46% in the integrated and with 24–27 and 27–31% in the organic orchards, respectively.

Scab incidence in the integrated orchard

Analyses of variance on spur-leaf cluster scab, leaf scab and fruit scab indicated significant differences ($P < 0.05$) between years, cultivars and sanitation treatments (Table 3).

Scab incidences were significantly lower for cv. Elstar compared to cv. Jonagold (P = 0.043 in 2003 and P = 0.028 in 2004), and in 2003 compared to 2004 (P = 0.033) (Table 6). In both years, treatment of leaf collection combined with plastic foil cover (Collect-L + Plastic-F) resulted in significantly lower ($P < 0.05$) scab incidence on spur-leaf clusters of both cultivars and on

Table 4. Effect of sanitation treatments on incidence of LLD (%) in an integrated apple orchard at Nagykálló and in an organic apple orchard at Eperjeske in Hungary (2002–2004)

	2002/2003[a]			2003/2004[a]		
	December 2002	March 2003	May 2003	December 2003	March 2004	May 2004
Integrated orchard						
Lime-S	85.6[b] c[c]	75.4 c	20.3 d	84.3 c	60.1 c	21.2 d
Collect-L	17.9 b	16.5 b	5.2 b	15.8 b	12.1 b	6.9 b
Mulch-C[d]	81.5 c	70.9 c	13.5 c	83.1 c	57.4 c	13.1 c
Lime-S + Mulch-C[d]	84.7 c	71.5 c	14.8 c	81.6 c	55.8 c	12.5 c
Collect-L + Mulch-C[d]	15.6 b	12.7 b	6.1 b	13.4 b	10.8 b	5.9 b
Collect-L + Plastic-F	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
Non-sanitized control	83.4 c	79.5 c	22.9 d	89.2 c	60.2 c	21.4 d
F-test (*P* value)[e]	***	***	**	***	***	**
Organic orchard						
Lime-S	72.2 c	66.9 c	7.8 b	76.3 c	53.6 c	8.4 b
Collect-L	10.7 b	11.1 b	1.8 a	12.6 b	7.9 b	1.6 a
Mulch-C[d]	75.3 c	64.7 c	7.7 b	78.4 c	50.8 c	7.9 b
Lime-S + Mulch-C[d]	71.2 c	63.9 c	6.5 b	74.6 c	51.6 c	7.9 b
Collect-L + Mulch-C[d]	8.9 b	7.9b	1.2 a	9.4 b	6.1 b	1.3 a
Collect-L + Plastic-F	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
Non-sanitized control	76.5 c	68.2 c	8.2 b	77.4 c	55.8 c	8.7 b
F-test (*P* value)[e]	***	***	*	***	***	**

[a]Percent data are shown as back-transformed means from arcsine Y = arcsine $[\%]^{1/2}$ values; therefore, no SED values are available.
[b]Means of 4 treatment replicates.
[c]Values within columns followed by different letters are significantly different. LSD t-test was used for comparing treatments.
[d]LLD was measured under the mulch cover on the orchard floor in March and May.
[e]*, ** and *** are significantly different from the santitation mean at 0.05, 0.01, and 0.001, respectively.

harvested fruits of cv. Jonagold compared to non-sanitized plots. Treatment of leaf collection combined with mulch cover (Collect-L + Mulch-C) reduced significantly ($P < 0.05$) scab incidence on spur-leaf clusters of cv. Jonagold in both years, on spur-leaf clusters of cv. Elstar in 2003, and on harvested fruits of cv. Jonagold in 2004. Moreover, application of leaf collection alone (Collect-L) significantly ($P < 0.05$) reduced scab incidence on spur-leaf clusters of cv. Jonagold in 2004 and of cv. Elstar in 2003 compared to non-sanitized plots. On both cultivars, treatments of lime sulphur and application of mulch cover alone (Lime-S, Lime-S + Mulch-C and Mulch-C) showed no significant reduction of scab incidence.

Scab incidence in the organic orchard

Similarly to the integrated orchard, analyses of variance on spur-leaf cluster scab, leaf scab and fruit scab indicated significant differences ($P < 0.05$) between years, cultivars and sanitation treatments (Table 3). For leaf scab and fruit scab, there was a significant year × cultivar interaction but this was not as dominating as the main effect of year or cultivar (Table 3).

Scab incidences were generally higher in the organic orchard on both cultivars and years compared to the integrated one (Tables 6 and 7). Similarly to the integrated orchard, scab incidences were significantly lower on the moderately susceptible cultivar (Jonathan) compared to cv. Jonagold ($P = 0.022$ in 2003 and $P = 0.013$ in 2004) (Table 7). In both years, scab incidence on cv. Jonathan was significantly lower ($P < 0.05$) only on spur-leaf clusters in the treatment of leaf collection combined with plastic foil cover (Collect-L + Plastic-F), compared to non-sanitized plots (Table 7). On cv. Jonagold, treatments of leaf collection combined with plastic foil cover (Collect-L + Plastic-F) and of leaf collection combined with mulch cover (Collect-L + Mulch-C) significantly reduced ($P < 0.05$) scab incidence on spur-leaf clusters, leaves and harvested fruits in

Table 5. Percent reduction of *V. inaequalis* ascospores trapped from an integrated apple orchard at Nagykálló and from an organic apple orchard at Eperjeske in Hungary in seven sanitation treatments (2003 and 2004)

	2003		2004	
	Elstar	Jonagold	Elstar	Jonagold
Integrated orchard				
Lime-S	5.4[a] d[b]	6.5 d	5.1 d	14.6 de
Collect-L	67.7 b	55.7 b	78.9 b	64.4 b
Mulch-C	38.0 c	31.5 c	36.6 c	36.8 cd
Lime-S + Mulch-C	39.9 c	40.3 bc	46.4 c	43.2 bc
Collect-L + Mulch-C	89.8 a	89.4 a	87.1 ab	92.2 a
Collect-L + Plastic-F	99.8 a	99.5 a	99.7 a	99.7 a
Non-sanitized control	0.0 d	0.0 d	0.0 d	0.0 e
F-test (*P* value)[c]	*	***	*	**
	Jonathan	Jonagold	Jonathan	Jonagold
Organic orchard				
Lime-S	4.1 d	1.3 d	1.1 d	1.1 d
Collect-L	60.8 b	65.3 b	62.7 b	60.8 b
Mulch-C	25.4 c	25.7 c	24.1 c	26.6 c
Lime-S + Mulch-C	30.9 c	26.7 c	28.0 c	26.9 c
Collect-L + Mulch-C	78.6 ab	73.4 ab	75.9 ab	72.5 b
Collect-L + Plastic-F	95.9 a	95.2 a	96.8 a	97.6 a
Non-sanitized control	0.0 d	0.0 d	0.0 d	0.0 d
F-test (*P* value)[c]	***	***	**	***

[a]Means of 4 treatment replicates of trapped ascospore number from March to end-May. Percent reduction of trapped ascospores ($R\%$) was estimated as $R\% = [(\mathrm{NST} - \mathrm{ST})/\mathrm{NST}] \times 100$ where ST is the total number of ascospores collected from a sanitized treatment, and NST is the total number of ascospores collected from a corresponding non-sanitized treatment. Percent data are shown as back-transformed means from arcsine $Y = \text{arcsine } [\%]^{1/2}$ values; therefore, no SED values are available.
[b]Values within columns followed by different letters are significantly different. LSD *t*-test was used for comparing treatments.
[c,*,] ** and *** are significantly different from the santitation mean at 0.05, 0.01 and 0.001, respectively.

both years. Moreover, a single application of leaf collection (Collect-L) significantly ($P < 0.05$) reduced scab incidence on spur-leaf clusters in both years and on harvested fruits in 2004, compared to non-sanitized plots. Similarly to the integrated orchard, treatments of lime sulphur and application of mulch cover alone (Lime-S, Lime-S + Mulch-C and Mulch-C) showed no significant reduction of scab incidence.

Discussion

The present study demonstrated that the six evaluated sanitation treatments, except for the application of lime sulphur alone, resulted in a significant reduction of LLD and ascospore production in both the integrated and organic apple orchards. However, only treatments of leaf collection applied alone or in combination with straw mulch or with plastic foil cover reduced significantly leaf or fruit scab incidence compared to non-sanitized plots.

The results of this study, in agreement with earlier studies (Sutton et al., 2000; Vincent et al., 2004), showed that LLD decreased more rapidly in the sanitized treatment plots from late autumn until spring, compared to non-sanitized plots (Table 4). Sutton et al. (2000) demonstrated that the shredding of leaf litter in autumn significantly ($P < 0.05$) reduced the amount of leaf litter by a mean of 52% at bud break in eight integrated orchards in New Hampshire and Maine, USA. In this study, it was demonstrated that leaf collection alone or in combination with mulch or with plastic foil cover resulted in a higher than 52% reduction of LLD by early spring (Table 4). It was also showed that reduction of LLD by sanitation treatments was faster by mid-May in the organic orchard compared to the integrated one (Table 4). Leaf degradation of tree species is highly dependent upon soil microbial and earthworm activities (Haynes, 1981; Paoletti et al., 1998); and recent studies (Glover et al., 2000; Reganold et al., 2001) indicated that these soil biological properties increased more rapidly in an organic apple orchard after a minimum of 3 years of organic soil

Table 6. Effect of sanitation treatments on incidence of apple scab on spur-leaf clusters, leaves and fruits of cvs. Jonagold and Elstar in an integrated apple orchard at Nagykálló in Hungary (2003 and 2004)

	Spur-leaf cluster[a]		Leaf[a]		Fruit[a]	
2003	Elstar 27 May	Jonagold	Elstar 22 June	Jonagold	Elstar 5 October	Jonagold
Lime-S	1.2[b] b[c]	2.9 c	3.2 b	4.9 ab	1.0 ab	3.3 b
Collect-L	0.0 a	1.7 abc	2.0 ab	3.8 ab	0.0 a	2.5 ab
Mulch-C	0.7 ab	2.5 bc	3.0 ab	4.6 ab	0.5 ab	2.8 ab
Lime-S + Mulch-C	0.9 b	2.7 c	3.0 ab	4.9 ab	0.7 ab	2.7 ab
Collect-L + Mulch-C	0.0 a	1.1 ab	2.0 ab	3.5 ab	0.0 a	2.3 ab
Collect-L + Plastic-F	0.0 a	0.7 a	1.8 a	3.0 a	0.0 a	1.9 a
Non-sanitized control	1.3 b	2.7 c	3.3 b	5.2 b	1.1 b	3.2 b
F-test (*P* value)[d]	*	*	+	+	+	*
2004	23 May		25 June		3 October	
Lime-S	3.0 b	4.7 c	6.0 –	10.5 ab	7.9 b	12.0 bc
Collect-L	2.0 ab	3.4 b	5.3 –	8.5 ab	6.3 ab	10.8 abc
Mulch-C	2.6 ab	4.1 bc	5.7 –	9.9 ab	7.2 ab	12.5 c
Lime-S + Mulch-C	2.6 ab	3.9 bc	5.6 –	9.0 ab	7.0 ab	12.0 bc
Collect-L + Mulch-C	2.0 ab	3.1 ab	4.9 –	8.1 ab	6.2 ab	8.7 ab
Collect-L + Plastic-F	1.8 a	2.1 a	4.6 –	7.1 a	5.6 a	8.1 a
Non-sanitized control	3.1 b	4.7 c	6.1 –	10.9 b	7.9 b	12.3 c
F-test (*P* value)[d]	*	**	ns	+	+	*

[a]Incidence data are shown as back-transformed means from arcsine Y = arcsine $[\%]^{1/2}$ values; therefore, no SED values are available.
[b]Means of 4 treatment replicates.
[c]Values within columns followed by different letters are significantly different. LSD *t*-test was used for comparing treatments.
[d], +, *, ** and *** are significantly different from the santitation mean at 0.1, 0.05, 0.01 and 0.001, respectively.

management, compared to an integrated or a conventional orchard, which might enhance leaf decomposition in organic orchards. Soil microbial and earthworm activities were not measured in our orchards; in some years large leaf degradation differences could be seen from orchard to orchard even if they had close to similar spray regimes (Holb, University of Debrecen, Hungary, unpubl.). Therefore, further multi-year and multi-orchard studies are needed for justifying leaf degradation differences between integrated and organic orchards.

Our study, similarly to earlier findings (Sutton et al., 2000; Vincent et al., 2004), demonstrated that sanitation treatments reduced ascospore production of *V. inaequalis* by 25–99% depending on cultivar susceptibility, disease management and year (Table 5). The largest reduction of ascospore production (99.5–99.8% in the integrated and 95.2–97.7% in the organic orchard) was shown by leaf collection combined with plastic foil cover (Table 5). However, in earlier studies by Holb et al. (2004a, b), plastic foil cover applied alone reduced ascospore production by 99.9% in an organic orchard over 45 m from the inoculum sources. In this study, the lower efficacy of leaf collection combined with plastic cover may be due to smaller experimental plots and subsequent spore transportation from other less effective sanitation treatments plots. Leaf collection combined with mulch cover also seemed to be an effective sanitation method especially in the integrated orchard (Table 5). Aylor (1998) indicated that wind speed near the ground of an orchard with tall *Festuca arundinacea* grass alley was only 11% that of an orchard without a grass alley. Consequently, the presence of a grass alley significantly reduced the escape of ascospores from the ground-level of infected leaf litter. A similar effect might be supposed in our treatments of 10 cm mulch-layer cover, which resulted in a significantly lower number of trapped ascospores compared to those trapped from non-sanitized plots. However, this study also demonstrated that the higher the inoculum source in the orchard (e.g. in organic orchard), the lower the mulching effect on trapped ascospores, either applied alone or in combination with leaf collection (Table 5).

Table 7. Effect of sanitation treatments on incidence of apple scab on spur-leaf clusters, leaves and fruits of cvs. Jonagold and Jonathan in an organic apple orchard at Eperjeske in Hungary (2003 and 2004)

	Spur-leaf cluster [a]		Leaf [a]		Fruit [a]	
2003	Jonathan 25 May	Jonagold	Jonathan 24 June	Jonagold	Jonathan 7 October	Jonagold
Lime-S	2.8[b] b[c]	5.0 bc	13.0 –	24.7 c	9.7 –	23.9 c
Collect-L	2.0 ab	3.4 ab	10.7 –	21.3 abc	8.2 –	20.4 bc
Mulch-C	2.5 b	4.9 bc	12.9 –	22.8 bc	9.4 –	22.7 bc
Lime-S + Mulch-C	2.4 b	4.7 bc	12.5 –	22.5 bc	9.4 –	22.4 bc
Collect-L + Mulch-C	1.7 ab	3.1 ab	10.3 –	18.9 ab	7.6 –	19.8 ab
Collect-L + Plastic-F	1.2 a	2.5 a	9.9 –	17.9 a	6.8 –	18.2 a
Non-sanitized control	2.8 b	5.4 c	13.0 –	24.7 c	9.6 –	24.1 c
F-test (*P* value)[d]	*	*	ns	*	ns	*
2004	22 May		27 June		2 October	
Lime-S	5.0 b	7.5 c	23.2 -	36.7 c	16.9 b	44.1 c
Collect-L	3.3 ab	4.1 ab	20.7 -	34.5 bc	15.1 ab	38.3 ab
Mulch-C	4.3 b	5.7 abc	22.5 -	35.7 bc	16.3 ab	43.1 bc
Lime-S + Mulch-C	4.2 ab	5.1 abc	22.7 -	35.3 bc	14.8 ab	42.3 abc
Collect-L + Mulch-C	3.0 ab	3.8 ab	20.4 -	32.3 ab	14.1 ab	37.4 a
Collect-L + Plastic-F	2.1 a	3.1 a	19.8 -	30.9 a	13.4 a	36.9 a
Non-sanitized control	4.8 b	7.9 c	23.3 -	36.8 c	16.5 b	43.7 c
F-test (*P* value)[d]	*	**	ns	*	+	*

[a]Incidence data are shown as back-transformed means from arcsine Y = arcsine $[\%]^{1/2}$ values; therefore, no SED values are available.
[b]Means of 4 treatment replicates.
[c]Values within columns followed by different letters are significantly different. LSD *t*-test was used for comparing treatments.
[d, +,*, ** and *** are significantly different from the santitation mean at 0.1, 0.05, 0.01 and 0.001, respectively.

Despite the considerable ascospore reduction potential of the present study's sanitation treatments, reduction potentials of the treatments on scab incidence of spur-leaf clusters, leaves and harvested fruits were lower than on corresponding ascospore production (Tables 5–7). Spore transportation from other less effective sanitation treatment plots was likely to weaken the scab reduction potential of all treatments on spur-leaf clusters. Moreover, decreasing sanitation effects on leaves and harvested fruits compared to spur-leaf clusters may also be due to the exponential increase of disease development later in the season (Holb et al., 2003b, 2005b). It is probable that under the same conditions, in those integrated orchards where only one sanitation treatment (e.g. Collect-L + Mulch-C) is used in a large field, a grower can reach a better sanitation potential on spur-leaf incidence, as ascospore transportation from other less effective sanitation treatments is excluded.

In an organic apple orchard, the presence of large ascosporic inoculum sources greatly reduces the efficacy of scab control. Therefore, in these orchards, sanitation treatments aimed at destroying overwintering pseudothecia play a role of great importance in scab management. In this study, leaf collection treatments (Collect-L, Collect-L + Mulch-C, Collect-L + Plastic-F) showed great reduction on ascosporic inoculum sources (Tables 4 and 5). However, as earlier studies (Becker et al., 1992; Holb et al., 2004a) demonstrated, conidia could overwinter within the buds of an apple tree twig in orchards with large inoculum sources. Consequently, if most overwintered pseudothecia are eliminated from the ground of an organic orchard by sanitation, then it might be hypothesized that overwintered conida may assume a greater importance in early spring than ascospores. Therefore, control measures, such as winter pruning and/or a fungicide spray at the green-tip phenological stage (Holb et al., 2004a; Holb, 2005), will probably be needed in order to prevent infection by overwintering conidia in a well-sanitized organic orchard.

In order to test such control measures, the effect of winter pruning on apple scab was also investigated in the same organic orchard where the present study was made, in all above sanitation treatments and years on the same two apple cultivars. Two pruning treatments were performed: unpruned and pruned, where the upper third of all shoots of a tree was pruned according to Holb et al. (2004a). The results showed that the incidence of spur-leaf clusters was lower only on the scab susceptible cv. Jonagold and only in the pruned treatments of leaf collection combined with mulch or with plastic foil cover, compared to corresponding leaf collection treatments without pruning. The results were significant ($P < 0.05$) only in the spring of 2004 (Holb, unpublished). The low effect of pruning on apple scab in the sanitation treatments was probably due to the fact that considerable amounts of conidia could overwinter only on a scab susceptible cultivar (Holb et al., 2005a); considerable amounts of ascosporic inoculum were also present in most of the sanitized plots during the spring infection by overwintered conida, except for treatments of leaf collection combined with mulch or with plastic foil cover (Table 5). Furthermore, the only one-year (2004) effect of pruning indicated that temperature during winter might influence the survival of conidia inside buds in Hungary (the minimum temperatures in the winter months were significantly higher ($P < 0.05$) in 2003/2004, than those of 2002/2003). The result of pruning in the sanitized treatments indicated that high disease pressure and milder winter increase the importance of overwintered conida in a well sanitized orchard in Hungary; therefore, effective orchard sanitation needs to be combined with control measures against overwintered conidia in highly infested organic orchards.

In this study, leaf collection treatments (Collect-L, Collect-L + Mulch-C, Collect-L + Plastic-F) resulted in more than 50% sanitation effectiveness compared to non-sanitized treatments, which fulfills the sanitation potential criteria of MacHardy et al. (1993) and Sutton et al. (2000). Therefore, these treatments might be successful options in both integrated and organic orchard management practices. Use of plastic foil or geotextile cover is recommended by Swiss organic growing guidelines (Anon., 2001); however, their costs in commercial apple growing would probably be economically unacceptable. On the other hand, collection of fallen leaves from the ground can be incorporated into the general orchard management practice, as there are commercially available leaf collector adapters for most tractors and such collection can be performed in combination with other orchard management activities in autumn. Application of leaf collection can also benefit the reduction of the inoculum potential of other diseases (e.g. Alternaria blotch (caused by *Alternaria mali*) and pests (e.g. leafminers), which overwinter in apple leaves on the orchard floor (Filajdic and Sutton, 1995; Vincent et al., 2004). Furthermore, it is recommended making compost from the collected fallen leaves under a minimum peak temperature of 64–70 °C and for a minimum duration of 21 days, which are sufficient to reduce plant pathogens below detection limits (Noble and Roberts, 2004). The compost then can be used as natural manure for the nutrient supply of the orchard. This recommendation would be given a great priority in organic orchards where only pesticide-free farmyard manure or compost can be used as an orchard nutritional supply (Anon., 1989). In this study, it was also revealed that the sanitation potential of leaf collection can be increased by straw mulch cover of the orchard floor (Tables 4–7), in order to improve scab management in early spring. In addition to this, several studies showed that mulch cover increased the numbers of predatory arthropods (e.g. Culliney and Pimentel, 1985; Mathews et al., 2002), and decreased populations of spotted tentiform leafminer and migrating *Eriosoma lanigerum* nymphs (Brown and Tworkoski, 2004). Furthermore, mulch cover helped soil microbial and earthworm activities (e.g. Niklas et al., 1979; Haynes, 1981). On the other hand, straw mulch cover could also increase the incidence of Phytophthora crown and root rots of a tree (Merwin et al., 1992) and damage from the meadow vole (*Microtus pennsylvanicus*) (Merwin et al., 1999) in apple orchards. Therefore, further studies are needed to optimize the application properties of straw mulch cover (e.g. covering layer and duration of mulch cover) in general orchard management practice.

In summary, this was the first in-depth study to evaluate the sanitation potential of lime sulphur, mulch cover, leaf collection and their combinations on apple scab. Most of these sanitation treatments can be practically useful elements of apple scab control, although they reduce scab infections only partially, especially in organic apple orchards. Therefore, sanitation should be combined with other disease control methods, such as winter and summer tree pruning, the use of antagonists, plant inducers, and resistant cultivars, in order to achieve more efficient control.

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