Integrated Control of Apple Scab and Powdery Mildew in an Organic Apple Orchard by Combining Potassium Carbonates with Wettable Sulfur, Pruning, and Cultivar Susceptibility

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Abstract

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In a 4-year study in a whole-field sanitized organic apple orchard, the effectiveness of nine fungicide treatments, including potassium mono- and bicarbonate and their combinations with wettable sulfur, were evaluated for scab and powdery mildew control on two cultivars with different susceptibility to scab and powdery mildew, under two pruning treatments. The whole-field sanitation practice was performed by removal of infected fallen leaves. Treatment effects on phytotoxicity and yield were also determined. Pruning significantly reduced leaf scab incidence but only on the more scab-susceptible Idared. Pruning significantly reduced mildew incidence in most years and on both cultivars but the more mildew-susceptible Jonathan showed significantly higher mildew incidence than Idared. Among products approved for organic production, the best scab control was achieved with a potassium mono- or bicarbonate treatment combined with wettable sulfur, except for Jonathan in 2011 on leaf and in 2014 on both leaf and fruit, and for Idared in 2013 on fruit. The best mildew control was also achieved with potassium mono- or bicarbonate treatments combined with wettable sulfur, with exceptions on shoots of Idared in 2011 and 2013 and on fruit of Idared in 2012. Leaf phytotoxicity was significantly higher in all potassium carbonate treatments compared with untreated plots, except for Idared in 2012, while fruit russet in these treatments did not differ significantly from the untreated plots. However, phytotoxicity values of all carbonate treatments were significantly lower than the lime sulfur treatment in most years on both cultivars. Yield of the potassium mono- or bicarbonate treatments combined with wettable sulfur was significantly higher than the untreated plots in the pruned treatments for both cultivars in all years. The integrated control approach designed for organic disease management against the two pathogens is discussed.

In organic apple production, only limited, approved plant protection compounds are available against key fungal diseases such as apple scab caused by *Venturia inaequalis* (Cooke) G. Winter and powdery mildew caused by *Podosphaera leucotricha* (Ellis & Everh.) E. S. Salmon (Holb 2009; Holb et al. 2003; Reganold et al. 2001; Tamm et al. 2004). From these options, copper-based products and elemental and lime sulfur are considered the most effective compounds against apple scab and powdery mildew (Anonymous 2009; Holb 2009).

Copper is effective against apple scab but, for environmental reasons, the European Union Council Regulation (EC Number 473/2002) allows only a reduced input of copper fungicides. In some Western and Northern European countries, the use of copper fungicides is no longer allowed. The remaining options for apple scab control are some promising biological control options (Carisse et al. 2000; Köhl et al. 2015) as well as elemental and lime sulfur products (Holb et al. 2003; Jamar et al. 2008). Sulfur compounds are often less effective against apple scab than copper-based compounds and scab control may require more applications of sulfur compounds to compensate. On the other hand, sulfur compounds are the most effective materials against apple powdery mildew in organic production in order to reduce primary inoculum sources of *P. leucotricha* on susceptible cultivars (Holb 2009). Therefore, organic apple growers use large amounts of sulfur compounds against the two key fungal diseases. However, several studies showed that the repeated application of sulfur compounds had ecotoxicological side effects (Holb et al. 2003; Mills 1947; Palmer et al. 2003; Tweedy 1981), and could also lead to leaf phytotoxicity or reduced fruit quality (Holb et al. 2003; Jamar et al. 2008) as well as undesirable effects on beneficial fauna (Jamar et al. 2008; Kreiter et al. 1998). Typically, in an organic apple orchard, from 10 to 26 sprays may be applied against apple scab and powdery mildew in each season, depending on cultivar susceptibility, weather conditions, and the amount of inoculum (Holb 2006, 2009).

Because of the negative features of the standard sulfur or lime sulfur and copper fungicides, it is important to evaluate the effectiveness of other organically approved compounds that have no or little harmful effects on the environment and human health. Such known proming compounds are potassium carbonates, including mono- or bicarbonate compounds. They are common food additives or fertilizers allowed in many applications under European and North American regulations (Kelderer et al. 2006, 2008; Milling et al. 2012; Slatnar et al. 2012). In addition, they have been tested against several plant pathogens (Andrews et al. 2001; Babadoost et al. 2004; Milling et al. 2012; Punja and Grogan 1982) and used successfully against the sooty blotch/flyspeck disease complex in organic disease management practice (Mayr and Späth 2008). Recently, carbonates have also been tested against apple scab (Cromwell et al. 2011; Heijne et al. 2007; Holb 2009; Jamar and Lateur 2007; Jamar et al. 2007, 2008; Schulze and Schönherr 2003) and, to a lesser extent, against apple powdery mildew (Jamar and Lateur 2007; Mitre et al. 2010). Earlier reports supported a field dosage of 1.5% for bicarbonates but then a correction was made to a dosage of 0.5 to 1% in order to reduce phytotoxicity (Heijne et al. 2007). Bicarbonates were successfully used against apple scab in "during-infection" spray strategy (Jamar et al. 2008), though the potassium carbonates showed no direct curative activities against the pathogen (Schulze and Schönherr 2003). Recently, Hinze and Kunz (2010, 2012) and Milling et al. (2012) showed a 5- to 18-h after-infection activity of potassium mono- and bicarbonates against apple scab on in vivo potted 'Jonagold' apple trees. The practical experience of apple scab control with bicarbonates indicated that the highest efficacy occurs shortly after

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the moment the infection has started, which was also supported in field conditions by Kunz et al. (2008). Most of the potassium carbonate studies focused on bicarbonate (Ilhan et al. 2006; Philion and Joubert 2015), which is widely used in many fruit-growing regions. Only a few results are available on monocarbonate compounds, including their efficacy on apple scab (Kunz et al. 2008; Schulze and Schönherr 2003). In addition, limited scientific data are available on the effectiveness of potassium bicarbonate against powdery mildew (Jamar et al. 2007; Mitre et al. 2010) and no report is available on potassium monocarbonate compounds against apple powdery mildew.

Among several nonchemical approaches against apple scab—such as organically approved N sources facilitating leaf breakdown; leaf shredding; and sweeping, burying, and removal of infected fallen leaves—the most effective sanitation practice was leaf removal (Gomez et al. 2007; Holb 2006, 2007; Schupp 2004; Sutton et al. 2000). Its scab reduction activity was also confirmed in large field studies, and practical implementation efforts have been made as top organic growers widely use sanitation practice in some European countries (Holb 2006, 2009). In organic orchards, studies also showed that winter pruning was necessary to reduce overwintering conidia of apple scab inside bud scales to prevent early scab development on scab-susceptible cultivars (Holb 2008; Holb et al. 2004, 2005a,b). Pruning of mildew-infected terminal shoots is also known to be one of the most effective control approaches against primary mildew infection initiated from the surface of shoots or from inside the bud (Hickey and Yoder 1990; Holb 2014). Still, scab- or mildew-susceptible apple cultivars are grown in most organic apple orchards due to marketing constraints (Gessler et al. 2006; Holb 2009); therefore, leaf removal would need to be supplemented with winter pruning in order to improve scab and powdery mildew control.

It follows that scab and powdery mildew controls are strongly connected to each other both for epidemiology (such as overwintering in buds) and control options (such as winter pruning and potassium carbonate sprays). Therefore, an integrative approach against both diseases can be sufficiently effective in organic apple orchards. However, previous studies have not focused on combining nonchemical control methods with potassium carbonate sprays in order to show their joint potential against the two key diseases.

The general aim of this 4-year study was to evaluate integrative control options (fungicide application, pruning, and cultivar susceptibility) against apple scab and powdery mildew in organic apple production. Specifically, this study evaluated the effectiveness of nine fungicide treatments, including potassium mono- and bicarbonates and their combinations with wettable sulfur under two pruning regimes, aimed against both diseases, and on two cultivars with different susceptibility to scab and powdery mildew. A whole-orchard sanitation with removal of infected fallen leaves was performed. Effects of the treatments on leaf phytotoxicity, fruit russet, yield, and the correlations among them were also determined.

Materials and Methods

Orchard and plant material. The study was conducted in an organic apple orchard at Eperjeske, eastern Hungary (latitude 47.53°N and longitude 21.63°E), from 2011 to 2014. The orchard was planted in 1997 with eight apple cultivars, including four rows of Idared and Jonathan. All trees were on M.26 rootstocks and pruned to a spindle shape. Between-row spacing was 5 m and within-row spacing was 2 m. Trees have been grown according to the Hungarian organic production guidelines (Anonymous 1997a) derived from International Federation of Organic Agriculture Movements standards (Anonymous 1998, 2009) since planting of the orchard. The orchard soil type was a gray brown luvisolic soil (1.4% humus and 78% sand). Trees were maintained approximately 3.0 to 4.0 m tall during the 4-year assessment period. A 0.7-m wide strip of bare soil was maintained with an orchard rototiller (BF300; Agrosat Ltd., Nova, Hungary) in the rows, and grass was grown between rows. Winter pruning before bud break was carried out each year. Grass between rows was cut with an orchard flail mower three times per year (early June, early July, and early September). Drip irrigation was applied during dry periods in 2011 and 2013. A whole-orchard sanitation practice was performed in autumn of each year in order to remove scab-infected fallen leaves from the orchard floor. According to the study of Holb (2006), leaves were collected in the whole orchard area with a John Deere F-725 flail mower (Deere & Company, Moline, IL) associated with an accompanying bin after natural defoliation on 24, 29, 30, and 27 November 2010, 2011, 2012, and 2013, respectively. Then, collected leaves were composted and used as fertilizer in the orchard in early March in each year, as suggested by Holb (2006, 2009). Observations were made on Idared and Jonathan fruit differing in their susceptibilities to scab and powdery mildew. Idared is highly susceptible to scab and moderately susceptible to powdery mildew while Jonathan is moderately susceptible to scab and highly susceptible to powdery mildew (Holb 2005, 2009; Norton 1981).

Environmental monitoring. Rainfall (millimeters per day), mean daily temperature (degrees Centigrade per day), and potential

Table 1. Applied rates and number of sprays of fungicide treatments at various phenological stages in an apple orchard (Eperjeske, Hungary, 2011 to 2014)

	Applied rates (%) at phenological stages (number of sprays)[w]					
Fungicide treatments[x]	BBCH 9 (1)[y]	BBCH 15–56 (2 to 3)[z]	BBCH 57–69 (2)	BBCH 70, 71, 72 (3)	BBCH 72–79 (6 to 8)[y,z]	BBCH 91 (1)[y]
Po-Bicarb	–	0.6	0.4	0.6	–	–
Po-Carb	–	0.6	0.4	0.6	–	–
Wett-S	–	0.6	0.4	0.6	0.5	–
Lime-S	–	1.5	0.75	1.2	–	–
Conv-Difen	–	0.02	0.02	0.02	–	–
Conv-Dithian	–	0.05	0.05	0.05	–	–
Co-Hydr	0.5	–	–	–	–	0.5

[w] Application timing according to BBCH growth stage scale for apple fruit (Meier et al. 1994): BBCH 9 = green-tip stage; BBCH 15 = more leaves unfolded, not yet at full size; BBCH 56 = green bud stage, single flowers separating (still closed); BBCH 57 = pink flower bud stage; BBCH 69 = end of flowering, all petals fallen; and BBCH 70, 71, 72 = fruit set and fruit size up to 10 and 20 mm, respectively; BBCH 72 to 79 = fruit stage after fruit size of 20 mm; and BBCH 91 = after harvest before leaf fall. Number in parentheses indicate number of sprays during the given BBCH growth stage period; – indicates that sprays were not applied with the given active ingredient at the given BBCH growth stage.

[x] Treatment codes: Po-Bicarb = potassium bicarbonate, $KHCO_3$ (Vitisan); Po-Carb = potassium monocarbonate, K_2CO_3 (Omni Protect); Wett-S = wettable sulfur (Kumulus S); Conv-Difen = conventional systemic fungicide control, difenoconazole (Score 250 EC); and Conv-Dithian = conventional contact fungicide control, dithianon, (Delan 750 SC). For potassium carbonate treatments, application rates below 1% were used according to Tamm et al. (2006), Kelderer et al. (2008), and personal experience in order to reduce phytotoxicity.

[y] The entire orchard, including untreated plots, received sprays of copper hydroxide at BBCH 9 and BBCH 91 or sprays of Wett-S between BBCH 72 and BBCH 79.

[z] Two sprays were applied in 2011 and 2013 while three were applied in 2012 and 2014 between BBCH 15 and BBCH 56. Six sprays were applied in 2011 and 2013 while eight were applied in 2012 and 2014 between BBCH 72 and BBCH 79.

infection periods, based on the criteria of Mills and La Plante (1951), were recorded using a Metos Compact agrometeorological station (Pessl Instrument GmbH, Weiz, Austria) from 15 March to 15 June 2011, 2012, 2013, and 2014. A weather station was placed in the middle of the orchard, and sensors were positioned at a 1.5-m height from the ground.

Experimental design and treatments. The experimental design was a split-split plot with the 4 years as blocks, two cultivars with different susceptibility to scab and powdery mildew (Idared versus Jonathan) as main plots, two pruning treatments (pruning versus unpruned) as subplots, and nine fungicide treatments as sub-subplots.

The two cultivars with different disease susceptibilities were established for each year as main plots. Four 500-tree plots each were randomly placed in cultivar susceptibility treatment blocks. Each of these plots was subsequently divided into two 250-tree subplots corresponding to Idared and Jonathan.

Within each main plot, two pruning treatments were performed for each cultivar in each year. In treatment 1, the upper two-thirds of all shoots were pruned in order to reduce overwintered conidia of *V. inaequalis* (Holb et al. 2004, 2005a,b) and overwintered mycelia of *P. leucotricha* in dormant buds (Hickey and Yoder 1990; Holb 2014). Treatment 2 was an unpruned treatment without removal of the upper two-third of shoots. Both treatments were replicated four times and each consisted of a minimum of 50 trees/cultivar. Treatments were performed on 10, 14, 17, and 24 February 2011, 2012, 2013, and 2014, respectively. Pruning treatments were performed after regular horticultural pruning using the same trees in the four consecutive years.

Each pruning subplot was split further into sub-subplots corresponding to nine fungicide treatments: (i) potassium bicarbonate (Po-Bicarb), (ii) potassium monocarbonate (Po-Carb), (iii) wettable sulfur (Wett-S), (iv) lime sulfur (Lime-S), (v) Po-Bicarb + Wett-S (in combination, not tank mixed), (vi) Po-Carb + Wett-S (in combination, not tank mixed), (vii) conventional systemic fungicide difenoconazole (Conv-Difen), (viii) conventional contact fungicide dithianon (Conv-Dithian), and (ix) an untreated control (untreated). Treatments were replicated four times and five trees were used in each replication. Treatments were performed between Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie (BBCH)

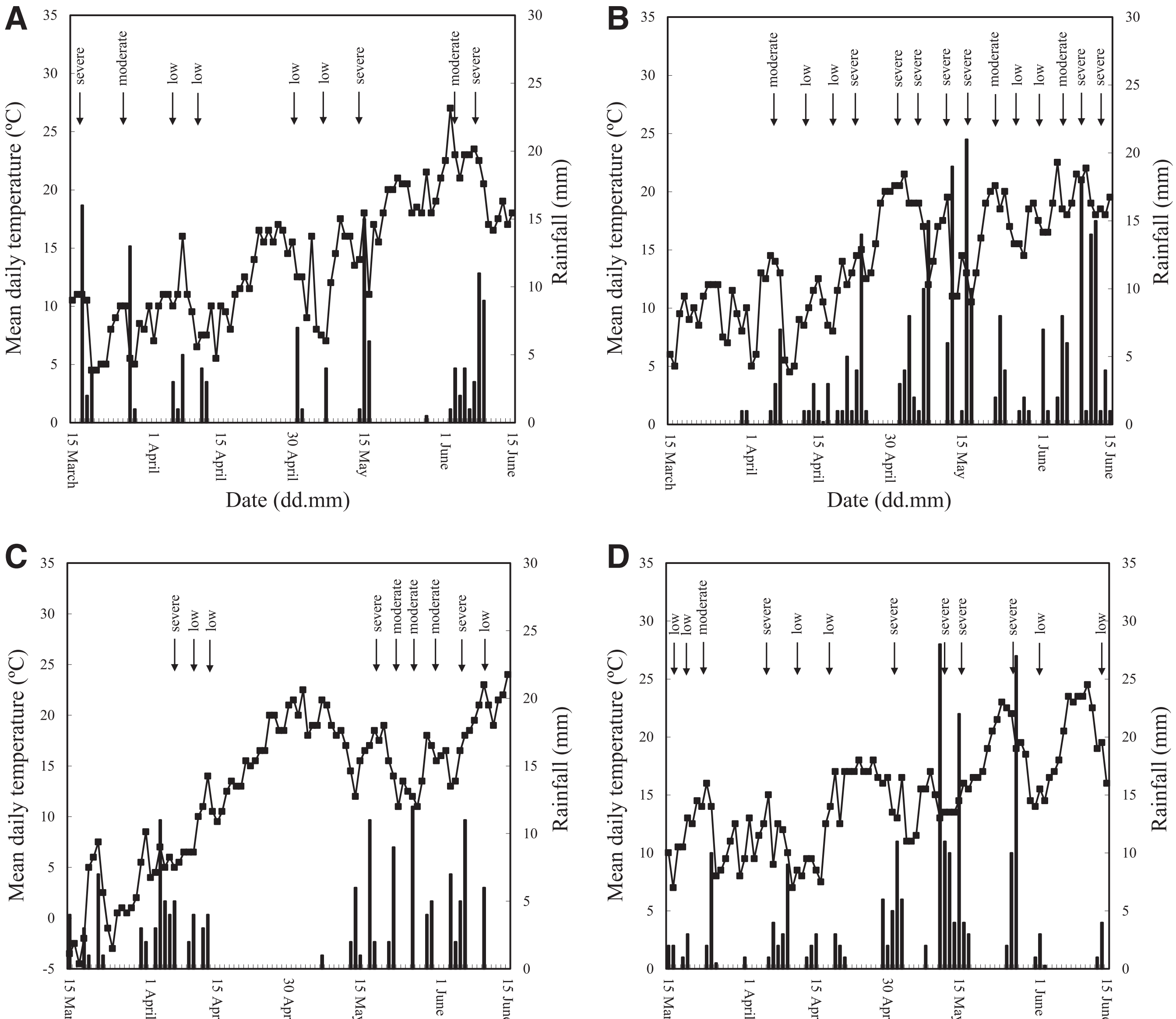

Fig. 1. Rainfall (bars) and mean daily temperature (squares) during **A,** 2011; **B,** 2012; **C,** 2013; and **D,** 2014 in Eperjeske, Hungary. Dates of Mills infection periods are represented with black arrows as severe, moderate, and low according to Mills and La Plante (1951).

growth stage 15 and (more leaves unfolded, not yet at full size) and growth stage 72 (fruit size up to 20 mm), including seven to eight sprays annually. Application rates and number of sprays at various phenological stages are listed in Table 1. Applied products were Kumulus S (80% Wett-S; BASF Hungaria Ltd., Budapest), Tiosol (29% calcium polysulphides; Tiosol Ltd., Kistelek, Hungary), Vitisan (Po-Bicarb = potassium hydrogen carbonate, $KHCO_3$, 99%; Biocont Ltd., Budapest), Omni Protect (Po-Carb = K_2CO_3, 99%; Bio-ferm GmbH, Tulln, Germany), Score 250 EC (difenoconazole at 250 g liter^{-1}; Syngenta Ltd., Budapest), and Delan 750 SC (dithianon at 750 g liter^{-1}; BASF Hungaria Ltd.). All sprays were applied with a handheld spray gun (Huneschans 18 3905 XL; EMPASS, Veenendaal, The Netherlands) with a ceramic hollow cone set at 1.1 to 1.2 MPa with a volume of 1,000 liters ha^{-1}.

All treatments of Po-Carb and Po-Bicarb as well as Lime-S were applied after infection onset at the moderate infection risk (between 150 and 300 DH), detected by the RIMpro scab warning system (Trapman 2001). Only treatment 3 with Wett-S was applied preventively because this compound has no during-infection or postinfection activity (Hamilton 1931; Holb et al. 2003).

All treatments (the entire orchard, including untreated plots) received 0.5% Wett-S (Kumulus S) at 7- to 16-day intervals, depending on weather conditions, after young fruit stage (BBCH 72 to 79 = fruit stages after fruit size of 20 mm) until the end of September, including six to eight sprays during this period (Table 1). A first and final spray of 1 and 0.5% copper hydroxide (Funguran-OH 50 WP, copper hydroxide, 77%; Spiess-Urania Chemicals GmbH, Hamburg, Germany) was also applied at BBCH 09 (green-tip stage) and after harvest in mid-October (BBCH 91 = after harvest, before leaf fall), respectively, in all treatments and in all years in order to reduce apple scab and fire blight inoculum (Table 1).

Scab and powdery mildew assessments. Scab assessments were made on both leaves and fruit of each experimental tree. For leaf assessment, 100 randomly selected leaves from each quadrant of a tree were examined for disease symptoms at 14 June 2011, 15 June 2012, 16 June 2013, and 15 June 2014, showing symptoms from primary scab infection. For fruit assessment, all fruit from each quadrant of a tree were assessed on the same dates in each year. A leaf or a fruit was considered diseased if at least one visible scab lesion was seen on the leaf or fruit. Values of leaf and fruit incidences from the quadrants were averaged to obtain the percentage of diseased leaves and fruit per tree, respectively.

Powdery mildew assessments were made on shoots and fruit of the same trees and assessment dates as for apple scab. All shoots and fruit from each quadrant of a tree were examined for disease symptoms. Shoots and fruit were considered diseased if at least one leaf was covered with mycelium or spores and if their surface was covered with a network pattern of corked cells (russet), respectively. Values from the quadrants were averaged to obtain the percentage of diseased shoots and fruit per tree.

Assessment of leaf phytotoxicity, fruit russet severity, and yield. Leaf phytotoxicity assessments were made on 50 randomly selected leaf clusters per tree at the same dates as for apple scab observation. Assessment was rated according to the scale of the study of Anonymous (1997b): 0 = no damage; 1 = cluster size 60 to 80% of normal size, no necrotic area on cluster; 2 = cluster size less than 60% of normal size, no necrotic area on cluster; 3 = cluster size less than 60% of normal size and necrotic area on cluster less than 3%; 4 = cluster size less than 60% of normal size and necrotic area on cluster 3 to 6%; and 5 = cluster size less than 60% of normal size and necrotic area on cluster more than 6%.

Table 2. Analysis of variance for the effects of year (2011, 2012, 2013, and 2014), cultivar (Jonathan versus Idared), pruning (pruned versus unpruned), and treatment (Po-Bicarb, Po-Carb, Wett-S, Lime-S, Po-Bicarb + Wett-S, Po-Carb + Wett-S, Conv-Difen, Conv-Dithian, and Untreated) on apple scab incidence (leaves and fruit) powdery mildew incidence (shoots and fruit), phytotoxicity (leaves and fruit), and yield in an organic apple orchard[w]

		Scab incidence(%)[x]			Powdery mildew incidence (%)[x]			Phytotoxicity			Yield		
Source of variation	**df[y]**	**MS**	***F***	***P***	**MS**	***F***	***P***	**MS**	***F***	***P***	**MS**	***F***	***P***
On leaves, shoots[z]													
Year (Y)	3	339.96	23.08	0.0142	180.77	12.28	0.0343	0.11	8.91	0.0497	154.81	79.94	0.0006
Cultivar (C)	1	1721.56	116.86	0.0017	1620.73	110.09	0.0018	0.21	17.49	0.0249	97.51	50.36	0.0014
Main plot error	3	14.73	…	…	14.72	…	…	0.011	…	…	0.74	…	…
Pruning (P)	1	77.88	19.17	0.0001	985.43	101.45	<0.0001	0.004	0.29	0.6117	102.85	12.37	0.0126
C × P	1	6.28	1.55	0.0511	106.95	11.01	0.0560	0.081	3.23	0.0632	3.77	0.45	0.5257
Subplot error	6	3.00	…	…	9.71	…	…	0.015	…	…	8.31	…	…
Treatment (T)	8	480.31	118.22	<0.0001	542.43	149.58	<0.0001	4.99	227.1	<0.0001	354.97	183.31	<0.0001
C × T	8	11.22	2.75	0.0507	29.75	8.20	0.0356	0.009	0.43	0.9092	1.61	0.83	0.5789
P × T	8	1.79	0.44	0.8930	16.83	4.64	0.0618	0.065	2.96	0.0553	1.13	0.59	0.7862
C × P × T	8	1.01	0.25	0.9801	3.37	0.93	0.4987	0.010	0.47	0.8765	0.29	0.15	0.9961
Sub-subplot error	47	4.06	…	…	3.63	…	…	0.022	…	…	1.93	…	…
On fruit													
Year (Y)	3	164.15	6.65	0.0469	145.55	32.25	0.0088	1.27	124.85	0.0012	…	…	…
Cultivar (C)	1	1091.20	44.23	0.0069	625.42	138.57	0.0013	0.87	12.85	0.0116	…	…	…
Main plot error	3	24.66	…	…	2.27	…	…	0.22			…	…	…
Pruning (P)	1	8.22	4.37	0.0393	299.58	137.66	<0.0001	0.054	5.35	0.1038	…	…	…
C × P	1	7.11	3.78	0.0549	33.16	15.24	0.0508	0.010	0.15	0.7141	…	…	…
Subplot error	6	0.34	…	…	4.51	…	…	0.007			…	…	…
Treatment (T)	8	165.82	88.10	<0.0001	192.99	84.88	<0.0001	7.58	161.70	<0.0001	…	…	…
C × T	8	7.35	3.89	0.0506	4.65	2.05	0.0502	0.082	1.75	0.0966	…	…	…
P × T	8	0.18	0.11	0.9991	2.68	1.18	0.2611	0.046	0.99	0.4515	…	…	…
C × P × T	8	0.17	0.09	0.9994	0.49	0.22	0.9870	0.027	0.58	0.7951	…	…	…
Sub-subplot error	47	1.88	…	…	2.27	…	…	0.047	…	…	…	…	…

[w] Po-Bicarb = potassium bicarbonate, Po-Carb = potassium monocarbonate, Wett-S = wettable sulfur, Lime-S = lime sulfur, Conv-Difen = systemic fungicide control, Conv-Dithian = contact fungicide control, and Untreated = untreated control. MS = mean square, *F* = *F* test, and *P* = probability values from analyses of variance.

[x] Based on arcsine-square root transformed disease incidence data.

[y] Degree of freedom.

[z] Scab incidence and phytotoxicity on leaves and powder mildew incidence and phytotoxicity on shoots.

Fruit russet severity was assessed on all harvested fruit according to EPPO/OEEP standards (Anonymous 1997b), based on a scale of 1 to 4, where class 1 = no russet and class 2 = 1 to 11%, class 3 = 12 to 33%, and class 4 = >33% russetted fruit surface area. To quantify fruit russet severity, an index was calculated by the equation $FRSI = [(N_{class1}/N_t) \times 0] + [(N_{class2}/N_t) \times 6] + [(N_{class3}/N_t) \times 22.5] + [(N_{class4}/N_t) \times 66.5]$, in which *FRSI* = average percentage of fruit surface with russet; N_{class1}, N_{class2}, N_{class3}, and N_{class4} represent the number of fruit in each russet class; and N_t = total number of fruit. The coefficients 0, 6, 22.5, and 66.5 represent the median of the lower and upper boundaries of class 1, class 2, class 3, and class 4, respectively. The lower boundary of class 1 is 0 and the upper boundary of class 4 is 100.

Yield was determined by the weight of all fruit per tree and treatment at harvest. Fruit yield was recorded on 25, 26, 29, and 22 September for Jonathan and 3, 5, 7, and 2 October for Idared in 2011, 2012, 2013, and 2014, respectively.

Statistical analyses. Scab and powdery mildew incidence data were transformed to *angular* (Y = arcsine [$\%^{1/2}$]) before analysis to stabilize variance. No transformation was necessary for phytotoxicity and yield data based on data normality. Each data set was analyzed by split-split-plot analysis of variance (ANOVA) to evaluate the main effects of year, cultivar, pruning, fungicide treatment, and their interactions (SAS version 8.1; SAS Institute Inc., Cary, NC). For each data set, significant F tests ($P < 0.05$) were followed by a least significance difference (LSD) test for comparison of treatment means using $LSD_{0.05}$ values. In order to quantify the relationship between leaf phytotoxicity and yield and between fruit russet severity and yield, Pearson's correlation coefficients were calculated among the measures. Correlation analyses were done separately for the 4 years using GenStat 9 (release 9.1; Lawes Agricultural Trust, IACR, Rothamsted, UK).

Results

Environmental monitoring. Rainfall was 121.4, 245.2, 148.1, and 214.8 mm during the period of 15 March to 15 June 2011, 2012, 2013, and 2014, respectively (Fig. 1). Mean daily temperature was 13.9, 14.2, 12.7, and 14.8°C during the period of 15 March to 15 June 2011, 2012, 2013, and 2014, respectively (Fig. 1). Some 9, 14, 9, and 12 Mills infection periods were recorded from 15 March until 15 June in 2011, 2012, 2013, and 2014 respectively. The Mills infection periods were severe on three, seven, three, and five occasions; moderate on two, three, three, and one occasions; and low on four, four, three, and six occasions in 2011, 2012, 2013, and 2014, respectively (Fig. 1).

Apple scab incidence. ANOVA on apple scab incidence values indicated significant differences among years (P = 0.0142 and 0.0469) cultivars (P = 0.0017 and 0.0069), pruning (P = 0.0001 and 0.0393), and treatments (P < 0.0001 and 0.0001) for leaf and fruit, respectively. There were no significant interactions (Table 2).

On both leaf and fruit, the more scab-susceptible Idared showed significantly higher scab incidence compared with Jonathan (Tables 3 and 4). Pruning significantly reduced leaf scab incidence in 2011, 2012, and 2014 on Idared whereas fruit scab incidence was reduced only in 2012 on Idared (Tables 3 and 4).

Among fungicide treatments, conventional systemic fungicide treatments provided the best scab control on both leaf and fruit in each year, which was not significantly different from the conventional

Table 3. Apple scab incidence on leaves of Idared and Jonathan apple in nine fungicide treatments and two pruning treatments at mid-June in an organic apple orchard (Eperjeske, Hungary, 2011 to 2014)

	Apple scab incidence (%)[x]										
	2011		2012		2013		2014		All years		
Pruning, treatment[y]	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Overall[z]
Unpruned											
Po-Bicarb	16.1 b	8.8 b	23.9 d	14.1 bc	18.1 cd	9.1 b	27.8 cd	15.3 bc	21.5 cd	11.8 bc	16.7 cd
Po-Carb	15.9 b	8.7 b	22.7 cd	13.5 bc	16.9 bcd	8.4 b	26.3 cd	14.3 bc	20.4 bcd	11.2 bc	15.8 bcd
Wett-S	17.6 b	9.5 b	24.8 d	14.4 c	19.5 d	9.7 b	29.3 d	17.4 c	22.8 d	12.7 c	17.8 d
Lime-S	14.9 b	8.1 b	21.6 bcd	12.5 bc	16.4 bcd	8.3 b	23.4 bc	13.8 b	19.1 bcd	10.7 bc	14.9 bcd
Po-Bicarb + Wett-S	14.8 b	8.2 b	19.4 bc	11.3 bc	15.9 bc	8.3 b	21.4 b	12.5 b	17.9 bc	10.0 b	14.0 bc
Po-Carb + Wett-S	14.6 b	8.0 b	18.6 b	10.9 b	14.2 b	7.5 b	19.9 b	11.8 b	16.8 b	9.6 b	13.2 b
Conv-Difen	7.2 a	3.5 a	7.8 a	4.2 a	8.9 a	4.7 a	7.9 a	4.9 a	7.9 a	4.3 a	6.1 a
Conv-Dithian	8.4 a	4.5 a	10.3 a	6.4 a	9.2 a	4.9 a	11.9 a	7.2 a	10.0 a	5.8 a	7.9 a
Untreated	24.3 c	14.4 c	36.7 e	22.1 d	27.5 e	14.8 c	43.7 e	25.9 d	33.1 e	19.3 d	26.2 e
$LSD_{0.05}$	3.1	1.8	4.0	3.2	3.6	2.3	4.5	3.5	3.8	2.6	3.3
Pruned											
Po-Bicarb	13.5 b	9.1 b	19.4 cd	13.4 b	16.1 c	9.1 bc	24.2 de	15.4 cd	18.3 cd	11.8 bc	15.0 bc
Po-Carb	13.3 b	9.3 b	18.4 bcd	12.2 b	15.0 bc	9.4 bc	22.9 cde	15.2 cd	17.4 bcd	11.5 bc	14.5 bc
Wett-S	14.8 b	10.4 b	20.1 d	13.4 b	17.4 c	10.9 c	25.5 e	17.3 d	19.4 d	13.0 c	16.2 c
Lime-S	12.5 b	8.4 b	17.5 bcd	11.3 b	14.6 bc	8.9 bc	20.4 bcd	13.4 bc	16.2 bcd	10.5 bc	13.4 bc
Po-Bicarb + Wett-S	12.5 b	8.5 b	15.7 bc	10.4 b	14.2 bc	8.5 b	18.6 bc	12.2 bc	15.2 bc	9.9 b	12.5 b
Po-Carb + Wett-S	12.2 b	8.4 b	15.0 b	10.2 b	12.6 b	8.8 b	17.3 b	11.1 b	14.3 b	9.7 b	12.0 b
Conv-Difen	6.0 a	4.0 a	6.3 a	4.1 a	7.9 a	4.3 a	6.9 a	4.3 a	6.8 a	4.2 a	5.5 a
Conv-Dithian	7.1 a	4.3 a	8.4 a	5.3 a	8.2 a	5.1 a	10.4 a	6.9 a	8.5 a	5.4 a	6.9 a
Untreated	20.4 c	13.9 c	29.7 e	18.8 c	24.5 d	14.9 d	38.0 f	24.8 e	28.2 e	18.1 d	23.1 d
$LSD_{0.05}$	2.6	2.0	3.9	3.3	3.3	2.0	4.3	3.7	3.7	2.7	3.2
Overall unpruned	14.9 b	8.2	20.6 b	12.2	16.3	8.4	23.6 b	13.7	18.8 b	10.6	14.7
Overall pruned	12.5 a	8.5	16.7 a	11.0	14.5	8.9	20.5 a	13.4	16.0 a	10.4	13.2
$LSD_{0.05}$	2.3	ns	3.8	ns	ns	ns	3.0	ns	2.7	ns	ns

[x] Apple scab incidence data shown are back-transformed means from arcsine ($\%^{1/2}$) values. Values followed by the same letter are not significantly different according to least significant difference (LSD) test ($LSD_{0.05}$ at P = 0.05 level); ns = nonsignificant; therefore, letters are not applied here for showing significant differences.

[y] Treatment codes: Po-Bicarb = potassium bicarbonate, $KHCO_3$ (Vitisan); Po-Carb = potassium monocarbonate, K_2CO_3 (Omni Protect); Wett-S = wettable sulfur (Kumulus S); Conv-Difen = conventional systemic fungicide control, difenoconazole (Score 250 EC); and Conv-Dithian = conventional contact fungicide control, dithianon, (Delan 750 SC). For potassium carbonate treatments, application rates below 1% were used according to Tamm et al. (2006), Kelderer et al. (2008), and personal experience in order to reduce phytotoxicity.

[z] Overall year and cultivar.

contact fungicide treatment (Tables 3 and 4). These treatments provided significantly better control compared with all other products approved for organic production. All other products approved for organic production provided significant scab control on leaves and fruit compared with untreated plots for all years. From these treatments, the best control was achieved with Po-Carb or Po-Bicarb treatment combined with Wett-S, except for Jonathan in 2011 on leaf and in 2014 on both leaf and fruit, and for Idared in 2013 on fruit. Scab efficacy of Lime-S applied alone was similar to treatments of Po-Carb or Po-Bicarb treatment combined with Wett-S and they were not significantly different in either year or pruning treatment. Wett-S alone showed generally the lowest efficacy against scab in all years and on both plant parts.

Powdery mildew incidence. ANOVA on powdery mildew incidence values indicated significant differences among years (P = 0.0343 and 0.0088), cultivars (P = 0.0018 and 0.0013), pruning ($P < 0.0001$ and 0.0001), and treatments ($P < 0.0001$ and 0.0001) for shoots and fruit, respectively. There were no significant interactions, except for one case of cultivar–treatment interaction for fruit (P = 0.0356; Table 2).

On both shoots and fruit, the more mildew-susceptible Jonathan showed significantly higher mildew incidence compared with Idared (Table 2). Pruning significantly reduced mildew incidence on both plant parts in all years and on both cultivars, except for shoot incidence of Idared in 2012 and 2014 and fruit incidence of Idared in 2012 and 2013 (Tables 5 and 6).

Among fungicide treatments, the conventional systemic fungicide treatment provided the best powdery mildew control on both shoots and fruit in each year, which was not significantly different from the conventional contact fungicide treatment (Tables 5 and 6). Among active ingredients approved for organic production, Po-Carb or Po-Bicarb treatments combined with Wett-S were superior in mildew control in each year on both plant parts compared with other organically approved compounds, with exceptions on shoots of Idared in 2011 and 2013 and fruit of Idared in 2012. Po-Carb or Po-Bicarb treatments applied either alone or in combination with Wett-S resulted in improved powdery mildew control ($P < 0.05$) on leaves and fruit compared with untreated plots, with the exception of shoot incidence of Idared in 2013. Wett-S and Lime-S applied alone showed similar powdery mildew efficacy on shoots compared with treatments of Po-Carb or Po-Bicarb treatment combined with Wett-S and they were not significantly different in either year or pruning treatment. Mildew control on shoots was the lowest in the Po-Bicarb treatment applied alone among the organically approved treatments, with the exception of Idared in 2011.

Leaf phytotoxicity and fruit russet severity. ANOVA on leaf phytotoxicity and fruit russet values indicated significant differences among years (P = 0.0497 and 0.0012), cultivar (P = 0.0249 and 0.0116), and treatments ($P < 0.0001$ and 0.0001) for leaf and fruit, respectively; however, no significant effects were found for pruning treatments (Table 2). There were no significant interactions. Leaf phytotoxicity and fruit russet data are shown separately for years, cultivars, and fungicide treatments only (Table 7).

Leaf phytotoxicity was generally higher on Idared compared with Jonathan. Fruit russet values were significantly higher ($P < 0.05$) compared with leaf phytotoxicity values in all years and both cultivars (Table 7). Among fungicide treatments, compared with untreated plots, the conventional treatments did not cause significantly

Table 4. Apple scab incidence on fruit of Idared and Jonathan apple in nine fungicide treatments and two pruning treatments at mid-June in an organic apple orchard (Eperjeske, Hungary, 2011 to 2014)

	Apple scab incidence (%)[x]										
	2011		2012		2013		2014		All years		
Pruning, treatment[y]	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Overall[z]
Unpruned											
Po-Bicarb	8.4 b	4.0 b	15.0 cd	7.0 cd	8.3 b	3.2 b	16.4 c	6.7 bc	12.0 bc	5.2 c	8.6 bc
Po-Carb	8.1 b	3.8 b	13.9 bcd	6.3 bcd	8.5 b	3.3 b	15.7 bc	6.0 ab	11.6 bc	4.9 bc	8.2 bc
Wett-S	9.3 b	4.0 b	16.3 d	7.4 d	9.5 b	4.7 b	15.5 bc	8.0 c	12.7 c	6.0 c	9.3 c
Lime-S	8.0 b	3.4 b	13.1 bc	6.1 bcd	8.1 b	3.9 b	15.1 bc	4.8 ab	11.1 bc	4.6 bc	7.8 bc
Po-Bicarb + Wett-S	7.6 b	3.4 b	11.7 b	5.5 bc	8.9 b	3.5 b	13.8 bc	5.8 ab	10.5 bc	4.6 bc	7.5 bc
Po-Carb + Wett-S	7.3 b	3.3 b	11.1 b	5.1 b	8.2 b	3.3 b	12.6 b	6.1 bc	9.8 b	4.5 bc	7.1 b
Conv-Difen	3.7 a	1.9 a	4.2 a	2.0 a	4.3 a	2.1 a	5.0 a	2.9 a	4.3 a	2.2 a	3.3 a
Conv-Dithian	4.3 a	2.0 a	5.3 a	2.5 a	5.1 a	4.0 b	6.6 a	4.1 a	5.3 a	3.2 ab	4.2 a
Untreated	14.2 c	6.7 c	23.1 e	10.2 e	17.3 c	7.8 c	28.0 d	12.3 d	20.7 d	9.3 d	15.0 d
$LSD_{0.05}$	2.1	1.2	3.1	1.7	2.0	1.5	3.6	1.9	2.7	1.8	2.1
Pruned											
Po-Bicarb	7.6 b	3.5 b	13.4 cd	6.3 bc	7.8 b	4.2 bc	15.3 b	6.3 b	11.0 b	5.1 cd	8.0 bc
Po-Carb	7.3 b	3.4 b	12.4 bcd	6.5 bc	8.0 b	4.1 bc	14.6 b	6.5 bc	10.6 b	5.1 cd	7.8 bc
Wett-S	8.4 b	5.0 c	14.5 d	7.3 c	8.9 b	4.5 c	14.4 b	7.9 c	11.5 b	6.2 d	8.9 c
Lime-S	7.2 b	3.2 b	11.7 bcd	5.5 bc	7.6 b	3.8 abc	14.0 b	5.2 b	10.1 b	4.3 bc	7.2 bc
Po-Bicarb + Wett-S	6.9 b	3.1 b	10.4 bc	5.2 b	8.4 b	4.0 bc	12.8 b	5.7 b	9.6 b	4.5 bc	7.1 b
Po-Carb + Wett-S	6.6 b	3.1 ab	9.9 b	5.0 b	7.7 b	3.8 abc	11.7 b	5.5 b	9.1 b	4.3 bc	6.6 b
Conv-Difen	3.3 a	2.0 a	3.7 a	2.1 a	4.0 a	2.3 a	4.7 a	3.0 a	3.9 a	2.4 a	3.1 a
Conv-Dithian	3.8 a	2.0 a	4.7 a	3.0 a	4.8 a	2.8 ab	6.1 a	4.0 a	4.9 a	3.0 ab	3.9 a
Untreated	12.8 c	6.1 d	20.6 e	10.8 d	16.3 c	8.2 d	26.0 c	11.7 d	18.9 c	9.2 e	14.0 d
$LSD_{0.05}$	2.1	1.0	3.0	1.9	2.5	1.6	3.9	1.4	2.4	1.6	1.7
Overall unpruned	7.9	3.6	12.6 b	5.8	8.7	4.1	14.3	6.3	10.9	4.9	7.9
Overall pruned	7.1	3.5	11.2 a	5.7	8.2	4.1	13.3	6.2	10.0	4.9	7.4
$LSD_{0.05}$	ns	ns	1.3	ns	ns	ns	ns	ns	ns	ns	ns

[x] Apple scab incidence data shown are back-transformed means from arcsine ($\%^{1/2}$) values. Values followed by the same letter are not significantly different according to least significant difference (LSD) test ($LSD_{0.05}$ at P = 0.05 level); ns = nonsignificant; therefore, letters are not applied here for showing significant differences.

[y] Treatment codes: Po-Bicarb = potassium bicarbonate, $KHCO_3$ (Vitisan); Po-Carb = potassium monocarbonate, K_2CO_3 (Omni Protect); Wett-S = wettable sulfur (Kumulus S); Conv-Difen = conventional systemic fungicide control, difenoconazole (Score 250 EC); and Conv-Dithian = conventional contact fungicide control, dithianon, (Delan 750 SC). For potassium carbonate treatments, application rates below 1% were used according to Tamm et al. (2006), Kelderer et al. (2008), and personal experience in order to reduce phytotoxicity.

[z] Overall year and cultivar.

more damage on leaves and significantly reduced damage to fruit ($P < 0.05$), except for Idared in 2013 (Table 7). Leaf phytotoxicity was significantly higher ($P < 0.05$) in the four potassium carbonate treatments compared with untreated plots, except for Idared in 2012, while fruit russet in these treatments did not differ significantly from the untreated plots. Lime-S treatments caused the highest phytotoxic damage on fruit and leaf in all years and both cultivars, which was significantly higher compared with the four carbonate treatments, except for fruit of Idared in 2011 and fruit of Jonathan in 2013 (Table 7).

Fruit yield. ANOVA on yield indicated significant differences among years ($P = 0.0006$), cultivar ($P = 0.0014$), pruning ($P = 0.0126$), and treatments ($P < 0.0001$). There were no significant interactions (Table 2).

Yield was generally higher in Idared compared with Jonathan (Table 8). Pruning significantly increased yield in 2011 and 2014 (Table 8). Among fungicide treatments, the conventional fungicide treatments provided the highest yield in each year on both cultivars and pruning treatments (Table 8), which were significantly different ($P < 0.05$) from the untreated plots. Yield in the treatments of Po-Carb or Po-Bicarb combined with Wett-S was significantly different ($P < 0.05$) from untreated plots in the pruned treatments for both cultivars and in all years. In the unpruned treatment, applications of Po-Carb or Po-Bicarb combined with Wett-S resulted in a consistently higher yield ($P < 0.05$) only in 2013 and 2014 on Idared compared with untreated plots (Table 8).

Relationships between leaf phytotoxicity and yield and between fruit russet severity and yield. Pearson's correlation coefficients showed that neither leaf phytotoxicity versus yield nor fruit russet severity versus yield correlated significantly to each other ($r = 0.188$ and 0.145 and $P = 0.5767$ and 0.6425 for 2011, $r = 0.211$ and 0.2122 and $P = 0.5378$ and 0.5246 for 2012, $r = 0.209$ and 0.167 and $P = 0.5378$ and 0.6223 for 2013, and $r = 0.182$ and 0.234 and $P = 0.6111$ and 0.4876 for 2014, for leaf phytotoxicity versus yield and fruit russet severity versus yield, respectively).

Discussion

Our study indicated that both potassium carbonate compounds significantly reduced apple scab and powdery mildew incidence during the primary infection periods compared with untreated plots under a whole-field sanitation approach, which was in agreement with previous studies. Efficacy of both potassium carbonate compounds was slightly increased when combined with Wett-S but was effective as a conventional treatment. Scab and powdery mildew incidences were further reduced by implementing pruning treatments on scab- and powdery-mildew-susceptible cultivars, respectively.

The overall incidences of scab were generally higher in 2012 and 2014 and lower in 2011 and 2013 while powdery mildew incidences were the opposite. The opposite behavior was largely due to the fact that different environmental conditions are favorable for the two diseases. Apple scab prefers rainy and relatively cold periods, with temperatures of 12 to 16°C (MacHardy and Gadoury 1989; Mills 1944), whereas powdery mildew requires an optimum of 20 to 22°C coupled with 70 to 100% relative humidity (Covey 1969; Hickey and Yoder 1990). Our results showed that there were higher amounts of precipitation and Mills infection periods in these years, indicating a higher scab risk compared with 2012 and 2014 (Fig. 1). Our results also supported the idea that the two diseases rarely develop into a severe epidemic in the same year under Hungarian continental climate zones

Table 5. Powdery mildew incidence on shoots of Idared and Jonathan apple in nine fungicide treatments and two pruning treatments at mid-June in an organic apple orchard (Eperjeske, Hungary, 2011 to 2014)

	Powdery mildew incidence (%)[x]										
	2011		2012		2013		2014		All years		
Pruning, treatment[y]	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Overall[z]
Unpruned											
Po-Bicarb	20.5 b	33.4 b	15.8 c	25.6 c	19.4 d	31.3 c	16.5 c	23.6 b	18.1 d	28.5 b	23.3 b
Po-Carb	21.1 b	31.9 b	14.9 bc	25.2 c	18.7 cd	29.4 c	15.3 bc	21.6 b	17.5 cd	27.0 b	22.3 b
Wett-S	19.2 b	30.0 b	13.2 bc	21.7 c	12.8 b	25.3 bc	13.8 bc	20.3 b	14.7 cd	24.3 b	19.5 b
Lime-S	17.8 b	28.4 b	10.9 b	20.2 c	14.3 bc	20.7 b	12.7 b	18.8 b	13.9 bcd	22.0 b	17.9 b
Po-Bicarb + Wett-S	17.8 b	27.5 b	10.7 b	18.6 bc	12.4 b	21.2 b	12.2 b	18.6 b	13.3 bc	21.4 b	17.4 b
Po-Carb + Wett-S	17.6 b	27.0 b	11.6 bc	19.4 bc	12.9 b	23.9 bc	11.8 b	18.3 b	13.5 bc	22.2 b	17.8 b
Conv-Difen	5.8 a	6.9 a	5.4 a	8.9 a	6.4 a	12.0 a	4.3 a	5.7 a	5.5 a	8.4 a	6.9 a
Conv-Dithian	7.9 a	10.8 a	12.8 bc	12.5 ab	11.8 ab	19.3 ab	5.2 a	9.2 a	9.4 ab	12.9 a	11.1 a
Untreated	28.7 c	45.2 c	20.2 d	34.1 d	23.1 d	39.1 d	20.1 d	33.6 c	23.0 e	38.0 c	30.5 c
$LSD_{0.05}$	5.2	8.7	4.6	7.4	4.8	7.7	3.5	7.1	4.5	8.0	6.2
Pruned											
Po-Bicarb	15.1 b	21.5 b	12.5 d	17.4 c	15.4 d	24.1 c	12.6 c	18.0 b	13.9 c	20.2 b	17.1 c
Po-Carb	14.6 b	20.5 b	12.1 d	17.2 c	14.8 cd	23.2 c	12.2 c	17.4 b	13.4 c	19.6 b	16.5 bc
Wett-S	13.1 b	19.2 b	11.0 cd	14.1 c	9.8 ab	15.7 b	9.2 b	13.8 b	10.8 bc	15.7 b	13.2 bc
Lime-S	13.4 b	19.1 b	9.3 bc	14.1 c	11.3 bc	16.8 b	8.8 b	13.2 b	10.7 bc	15.8 b	13.2 bc
Po-Bicarb + Wett-S	12.3 b	18.0 b	8.5 bc	13.2 bc	9.4 ab	15.4 b	8.7 b	13.1 b	9.7 b	14.9 b	12.3 b
Po-Carb + Wett-S	11.6 b	17.2 b	9.2 bc	13.4 c	9.8 ab	15.9 b	8.6 b	13.2 b	9.8 b	14.9 b	12.4 b
Conv-Difen	4.1 a	5.1 a	4.3 a	6.5 a	6.3 a	9.2 a	4.1 a	5.1 a	4.7 a	6.5 a	5.6 a
Conv-Dithian	5.8 a	7.2 a	7.8 b	9.0 ab	7.6 a	12.3 ab	4.7 a	7.2 a	6.5 a	8.9 a	7.7 a
Untreated	20.7 c	29.7 c	17.3 e	23.9 d	16.9 d	25.8 c	16.2 d	23.1 c	17.8 d	25.7 c	21.7 d
$LSD_{0.05}$	3.5	6.3	2.6	5.3	3.6	6.1	2.9	5.0	3.2	5.4	4.3
Overall unpruned	17.4 b	26.8 b	12.8	20.7 b	14.6 b	24.7 b	12.4	18.9 b	14.3 b	22.8 b	18.5 b
Overall pruned	12.3 a	17.5 a	10.2	14.3 a	11.3 a	17.6 a	9.5	13.8 a	10.8 a	15.8 a	13.3 a
$LSD_{0.05}$	4.2	7.4	ns	6.2	3.2	6.7	ns	5.0	3.2	6.6	5.0

[x] Powdery mildew incidence data shown are back-transformed means from arcsine($\%^{1/2}$) values. Values followed by the same letter are not significantly different according to least significant difference (LSD) test ($LSD_{0.05}$ at $P = 0.05$ level); ns = nonsignificant; therefore, letters are not applied here for showing significant differences.

[y] Treatment codes: Po-Bicarb = potassium bicarbonate, $KHCO_3$ (Vitisan); Po-Carb = potassium monocarbonate, K_2CO_3 (Omni Protect); Wett-S = wettable sulfur (Kumulus S); Conv-Difen = conventional systemic fungicide control, difenoconazole (Score 250 EC); and Conv-Dithian = conventional contact fungicide control, dithianon, (Delan 750 SC). For potassium carbonate treatments, application rates below 1% were used according to Tamm et al. (2006), Kelderer et al. (2008), and personal experience in order to reduce phytotoxicity.

[z] Overall year and cultivar.

(Tables 3 to 6) but one of them may become a key issue in a given year and need to be intensively controlled in organic orchards. However, this phenomenon was highly dependent on cultivar susceptibility to the disease. Cultivar susceptibility clearly indicated an epidemic fluctuation among years. In more rainy years (2012 and 2014), only scab caused a severe epidemic, and only on Idared, with a higher scab susceptibility. In dryer years (2011 and 2013), only powdery mildew became severe and only on Jonathan, with a higher mildew susceptibility. Both cultivars are highly appreciated by consumers; therefore, growers are forced to plant not only these but various cultivars in order to widen harvest period and fulfill consumer requirements. By doing so, growers can reduce harvest overload; however, the effectiveness of spray applications will be difficult to improve in the early season because repeated treatments must be done at least for one of the diseases. This phenomenon indicates that it is necessary to combine nonchemical options in order to effectively reduce primary inoculum sources of the two diseases. At present, this can only be done by pruning of primary inoculum sources of both diseases.

Our study indicated that pruning of the upper two-thirds of the shoots reduced incidence of both diseases on leaves and shoots of both cultivars. Previous research indicated that pruning of the upper two-thirds of the terminals can effectively reduce overwintering conidia of *V. inaequalis* (Holb 2005, 2008; Holb et al. 2004, 2005a,b). In addition, removal of infected terminals can also reduce powdery mildew incidence (Hickey and Yoder 1990; Holb 2014). However, this study was the first to consider jointly the effect of pruning on the two diseases under the same experimental conditions. For the growing practice, this means that not only the well-visible mildew-infected terminals should be removed during winter pruning but also the upper two-thirds of all terminals if leaf scab incidence reached the 40% threshold level in the previous autumn because this indicates a considerable number of overwintered conidia of *V. inaequalis* inside buds. However, the pruning treatments had a stronger effect on leaves than on fruit. This can be explained because pruning reduces the early inoculum sources associated with first green parts (leaves and flower sepals) in the buds (Hickey and Yoder 1990; Holb 2014) and, therefore, pruning may have only a delayed effect on the later-setting fruit. In addition, the disease reduction effect of pruning was nonsignificant in some years, especially for scab. The reason may be that fluctuating cold versus mild periods during winter critically reduced the viability of overwintered conidia in these years; therefore, these conidia caused only very few additional scab infections in the following early spring. As a consequence, the scab reduction potential of pruning could not be seen in such cases in pruned versus nonpruned treatments. Efficacy of pruning was also dependent on cultivar susceptibility for the two diseases. Scab reduction was stronger on scab-susceptible Idared due to removal of overwintered conidia of *V. inaequalis*, while the mildew reduction effect was stronger on the mildew-susceptible Jonathan due to the removal of overwintered mycelium of *P. leucotricha*.

Our study, in agreement with previous studies (Jamar et al. 2010; Kelderer et al. 2006, 2010; Tamm et al. 2004; Trapman 2008, 2009), indicated that Po-Bicarb treatments significantly reduced apple scab during the primary infection period compared with untreated plots. However, the reduction effect was lower in our study compared with the study of Mitre et al. (2009, 2010), which may be due to the use of different Po-Bicarb materials with different application rates and

Table 6. Powdery mildew incidence on fruit of Idared and Jonathan apple in nine fungicide treatments and two pruning treatments at mid-June in an organic apple orchard (Eperjeske, Hungary, 2011 to 2014)

	Powdery mildew incidence (%)[x]										
	2011		2012		2013		2014		All years		
Pruning, treatment[y]	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Overall[z]
Unpruned											
Po-Bicarb	15.1 d	24.2 d	6.9 a	12.3 a	8.5 bc	13.8 bc	10.0 c	15.6 d	10.2 c	16.5 cd	13.4 c
Po-Carb	12.3 cd	19.6 cd	6.1 a	10.7 a	7.2 abc	11.4 abc	8.6 bc	13.2 cd	8.6 bc	13.7 bc	11.2 abc
Wett-S	11.2 bcd	17.7 bcd	7.3 a	13.1 a	9.4 c	15.4 c	8.1 abc	12.6 bcd	9.0 bc	14.7 bc	11.9 bc
Lime-S	11.3 cd	18.0 cd	7.0 a	12.5 a	6.7 ab	11.3 abc	7.3 abc	10.7 abcd	8.1 abc	13.1 abc	10.6 abc
Po-Bicarb + Wett-S	8.8 abc	14.0 abc	6.5 a	11.5 a	5.9 abc	9.7 abc	6.0 ab	9.0 abc	6.8 abc	11.1 abc	9.0 abc
Po-Carb + Wett-S	7.6 abc	12.1 abc	5.0 a	9.0 a	4.8 ab	8.1 ab	5.3 ab	7.8 ab	5.7 ab	9.3 ab	7.5 ab
Conv-Difen	5.5 a	8.8 a	4.2 a	7.4 a	4.2 a	6.5 a	4.6 a	6.6 a	4.6 a	7.3 a	6.0 a
Conv-Dithian	6.3 ab	10.0 ab	6.0 a	10.7 a	6.4 abc	10.5 abc	5.0 ab	7.8 ab	5.9 abc	9.8 ab	7.9 ab
Untreated	20.1 e	31.8 e	12.9 b	21.3 b	13.6 d	22.7 d	13.7 d	20.7 e	15.0 d	24.1 d	19.5 d
$LSD_{0.05}$	4.9	7.5	4.4	6.7	4.1	6.1	3.6	5.0	4.3	6.3	5.3
Pruned											
Po-Bicarb	11.9 d	17.1 d	5.5 a	8.2 ab	6.4 b	10.2 bc	7.2 c	11.3 c	7.7 c	11.7 c	9.7 c
Po-Carb	9.5 cd	13.9 cd	4.9 a	7.2 ab	5.4 ab	8.5 abc	6.5 bc	9.6 bc	6.6 bc	9.8 bc	8.2 bc
Wett-S	8.8 bcd	12.6 bcd	5.9 a	8.8 b	7.1 b	11.6 c	6.2 bc	9.2 bc	7.0 bc	10.5 bc	8.8 bc
Lime-S	8.8 bcd	12.8 bcd	5.7 a	8.4 ab	5.0 ab	8.2 abc	5.1 abc	7.5 ab	6.1 abc	9.2 bc	7.7 abc
Po-Bicarb + Wett-S	6.7 abc	9.8 abc	5.1 a	7.7 ab	4.5 ab	7.3 abc	4.5 ab	6.7 ab	5.2 abc	7.9 abc	6.6 abc
Po-Carb + Wett-S	5.9 abc	8.6 ab	4.1 a	6.0 ab	3.6 a	6.0 ab	3.6 a	5.6 a	4.3 ab	6.6 ab	5.5 ab
Conv-Difen	4.4 a	6.3 a	3.4 a	5.0 a	2.9 a	4.8 a	3.0 a	4.5 a	3.4 a	5.1 a	4.3 a
Conv-Dithian	5.0 ab	7.0 a	4.7 a	7.1 ab	4.4 ab	7.9 abc	3.5 a	5.7 a	4.4 ab	6.9 ab	5.7 ab
Untreated	16.1 e	22.4 e	9.7 b	14.4 c	10.2 c	16.9 d	9.6 d	14.7 d	11.4 d	17.1 d	14.3 d
$LSD_{0.05}$	3.8	5.2	2.8	3.6	2.7	4.3	2.3	3.2	3.0	4.0	3.5
Overall unpruned	10.9 b	17.3 b	6.9	12.1 b	7.4	12.2 b	7.6 b	11.5 b	8.2 b	13.3 b	10.8 b
Overall pruned	8.6 a	12.3 a	5.4	8.1 a	5.5	9.0 a	5.5 a	8.3 a	6.2 a	9.4 a	7.9 a
$LSD_{0.05}$	2.2	4.7	ns	3.7	ns	3.1	2.0	3.0	1.9	3.7	2.7

[x] Powdery mildew incidence data shown are back-transformed means from arcsine($\%^{1/2}$) values. Values followed by the same letter are not significantly different according to least significant difference (LSD) test ($LSD_{0.05}$ at $P = 0.05$ level); ns = nonsignificant; therefore, letters are not applied here for showing significant differences.

[y] Treatment codes: Po-Bicarb = potassium bicarbonate, $KHCO_3$ (Vitisan); Po-Carb = potassium monocarbonate, K_2CO_3 (Omni Protect); Wett-S = wettable sulfur (Kumulus S); Conv-Difen = conventional systemic fungicide control, difenoconazole (Score 250 EC); and Conv-Dithian = conventional contact fungicide control, dithianon, (Delan 750 SC). For potassium carbonate treatments, application rates below 1% were used according to Tamm et al. (2006), Kelderer et al. (2008), and personal experience in order to reduce phytotoxicity.

[z] Overall year and cultivar.

frequencies in these studies. In our study, Po-Bicarb was as effective as elementary sulfur applied alone, in agreement with the studies of Tamm et al. (2006) and Jamar et al. (2010); and our study also confirmed an after-infection activity of this compound under field conditions, in agreement with previous studies of Hinze and Kunz (2010, 2012) and Milling et al. (2012). The after-infection activity of Po-Carb was demonstrated only under in vitro (Schulze and Schönherr 2003) and limited in vivo (Kunz et al. 2008) experimental conditions. However, our study also demonstrated the after-infection activity of Po-Carb under field conditions, not only alone but also in combination with Wett-S against apple scab. Overall, the efficacy of after-infection applications of both potassium carbonate compounds used alone was at least as good as elementary sulfur; therefore, we suggest that carbonates can replace the sulfur compound in order to reduce harmful effects on predatory mites. Some studies (Heijne et al. 2007; Mitre et al. 2009, 2010; Tamm et al. 2006) suggested that Po-Bicarb can be as effective as copper or Lime-S but detailed comparative studies were not done previously. In our study, only Lime-S was tested because Lime-S has considerable postinfection activity under field conditions in contrast with copper fungicides. Because copper is restricted or banned in several European countries and, therefore, used only as early spring or late autumn sprays (Holb 2009; Holb and Heijne 2001; Holb et al. 2003), its inclusion was not deemed useful. Our study clearly indicated that carbonate compounds alone cannot replace Lime-S against apple scab based on their lower efficacy. However, our study showed that both potassium carbonate compounds in combination with Wett-S were as effective as Lime-S (Tables 3 and 4); as a consequence, they may replace Lime-S under drier Central European climate conditions, too, as was suggested under different climate conditions (Kelderer et al. 2010; Philion and Joubert 2015). In addition, full or partial replacement of Lime-S with potassium carbonates is also supported by the fact that phytotoxicity and environmental risk features of potassium carbonates are significantly better than either copper or Lime-S (Jamar et al. 2008; Slatnar et al. 2012).

Results of this study on Po-Bicarb also showed a significant reduction in apple powdery mildew incidence, in agreement with the results of Jamar and Lateur (2007) and Milling et al. (2012). Under Romanian conditions, Mitre et al. (2009, 2010) proved not only that Po-Bicarb alone reduced powdery mildew incidence but also that its efficacy was similar to other approved compounds in organic production. Our study showed that efficacy of potassium carbonates in combination with Wett-S was better than carbonates applied alone and, to some extent, their efficacy on fruit was close to the conventional contact fungicide (Table 6). It is likely that there was an additive effect of using Po-Bicarb and Wett-S together against powdery mildew which resulted in an increased efficacy of Po-Bicarb. Apart from the direct control effect of Po-Bicarb on powdery mildews, this compound also acts as a potassium fertilizer, which decreases shoot susceptibility to powdery mildew. Sulfur, as a combination partner, also has direct killing effect on powdery mildew fungus (Wenneker and Kanne 2010). Previous studies are not available on the field activity of Po-Carb against apple powdery mildew but our study showed a similar efficacy of monocarbonate to the bicarbonate compound. According to our experience, the use of a mono- or bicarbonate compound can reduce the use of other organically approved compounds, especially sulfur, by at least 50% (I. J. Holb, unpublished). Because sulfur has good control efficacy against powdery mildew, the elimination of this compound can critically increase epidemic risk of this disease in organic production, especially on

Table 7. Phytotoxicity index of leaves and fruit in June on Idared and Jonathan apple in nine fungicide treatments (Eperjeske, Hungary, 2011 to 2014)

	Phytotoxicity index[x]										
	2011		2012		2013		2014		All years		
Plant part, treatment[y]	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Overall[z]
Leaves											
Po-Bicarb	1.8 b	1.9 b	2.1 bc	1.9 cd	2.0 bc	1.9 b	2.0 b	1.8 b	2.0 b	1.8 b	1.9 b
Po-Carb	1.8 b	1.8 b	1.7 bc	1.7 c	2.4 c	2.0 b	1.9 b	1.9 b	1.9 b	1.8 b	1.9 b
Wett-S	1.9 b	1.8 b	1.8 bc	1.7 c	1.8 b	1.8 b	1.9 b	1.8 b	1.8 b	1.7 b	1.8 b
Lime-S	3.2 c	3.1 c	3.8 d	3.6 e	3.4 d	3.1 c	3.3 c	3.7 c	3.4 c	3.3 c	3.4 c
Po-Bicarb + Wett-S	2.2 b	2.1 b	2.3 c	2.2 d	2.3 c	2.2 b	1.9 b	1.8 b	2.2 b	2.1 b	2.1 b
Po-Carb + Wett-S	2.2 b	2.1 b	2.3 c	2.2 d	2.3 c	1.9 b	2.0 b	1.7 b	2.2 b	2.0 b	2.1 b
Conv-Difen	0.7 a	0.6 a	0.9 a	0.7 ab	1.0 a	0.8 a	0.7 a	0.3 a	0.8 a	0.6 a	0.7 a
Conv-Dithian	0.6 a	0.5 a	0.6 a	0.4 a	0.9 a	0.7 a	0.7 a	0.5 a	0.7 a	0.5 a	0.6 a
Untreated	1.0 a	1.0 a	1.3 ab	1.1 b	1.2 a	1.1 a	0.9 a	0.8 a	1.1 a	1.0 a	1.1 a
$LSD_{0.05}$	0.7	0.7	0.7	0.4	0.5	0.6	0.4	0.5	0.6	0.6	0.5
Fruit											
Po-Bicarb	3.8 c	3.7 b	3.0 c	3.1 b	3.5 b	3.5 bc	3.1 c	2.8 b	3.3 c	3.3 b	3.3 b
Po-Carb	3.3 c	3.4 b	3.2 c	2.7 b	3.8 b	4.0 cd	3.7 c	3.7 b	3.6 c	3.5 b	3.5 b
Wett-S	3.7 c	4.0 b	2.7 bc	2.9 b	3.3 b	3.8 bcd	3.0 c	2.6 b	3.2 c	3.3 b	3.2 b
Lime-S	5.1 d	5.2 c	4.8 d	5.1 c	5.0 c	4.7 d	4.8 d	5.2 c	4.9 d	5.0 c	5.0 c
Po-Bicarb + Wett-S	3.2 bc	3.5 b	2.8 bc	2.9 b	3.8 b	4.0 cd	3.3 c	3.5 b	3.3 c	3.5 b	3.4 b
Po-Carb + Wett-S	4.1 cd	3.9 b	3.4 c	3.1 b	3.7 b	3.5 bc	3.1 c	2.9 b	3.6 c	3.3 b	3.5 b
Conv-Difen	2.1 ab	1.6 a	1.6 ab	1.2 a	1.8 a	1.4 a	1.9 ab	1.3 a	1.9 ab	1.4 a	1.6 a
Conv-Dithian	1.8 a	1.9 a	1.3 a	1.1 a	2.0 a	1.8 a	1.3 a	0.8 a	1.6 a	1.4 a	1.5 a
Untreated	3.0 bc	3.3 b	2.8 bc	2.7 b	2.9 ab	2.9 b	2.8 bc	3.1 b	2.8 bc	3.0 b	2.9 b
$LSD_{0.05}$	1.1	1.1	1.2	1.2	1.1	0.9	1.0	1.2	1.1	1.2	1.1
Overall leaf	1.7 a	1.6 a	1.8 a	1.7 a	1.9 a	1.7 a	1.7 a	1.6 a	1.8 a	1.7 a	1.7 a
Overall fruit	3.3 b	3.4 b	2.8 b	2.7 b	3.3 b	3.3 b	3.0 b	2.9 b	3.1 b	3.1 b	3.1 b
$LSD_{0.05}$	1.1	1.0	0.9	0.8	1.0	0.9	0.9	1.0	0.9	1.0	1.0

[x] Values followed by the same letter are not significantly different according to least significant difference (LSD) test ($LSD_{0.05}$ at $P = 0.05$ level); ns = nonsignificant; therefore, letters are not applied here for showing significant differences.

[y] Treatment codes: Po-Bicarb = potassium bicarbonate, $KHCO_3$ (Vitisan); Po-Carb = potassium monocarbonate, K_2CO_3 (Omni Protect); Wett-S = wettable sulfur (Kumulus S); Conv-Difen = conventional systemic fungicide control, difenoconazole (Score 250 EC); and Conv-Dithian = conventional contact fungicide control, dithianon, (Delan 750 SC). For potassium carbonate treatments, application rates below 1% were used according to Tamm et al. (2006), Kelderer et al. (2008), and personal experience in order to reduce phytotoxicity.

[z] Overall year and cultivar.

mildew-susceptible cultivars such as on Jonathan. However, reduced use of sulfur due to partial replacement with potassium carbonate compounds can effectively decrease the harmful effects of sulfur on predatory mites without reducing the efficacy of the overall powdery mildew control.

In this study, neither Po-Carb nor Po-Bicarb treatments below 1% dosages caused considerable phytotoxicity on leaf and fruit, in agreement with previous studies (Jamar et al. 2010; Mitre et al. 2010; Slatnar et al. 2012; Tamm et al. 2006; Trapman 2008). However, higher dosage of Po-Bicarb (above 1%) showed 3 to 6% fruit russet in previous studies (Jamar et al. 2008). In this study, we evaluated phytotoxic effects not only for Po-Bicarb but also for Po-Carb applied alone or in combination with Wett-S. Overall, our study indicates that both Po-Carb and Po-Bicarb in combination with sulfur are viable options in organic disease management, based on both phytotoxicity and efficacy issues.

Potassium carbonate treatments increased yield significantly in years with more precipitation (Table 8). In previous studies, Jamar et al. (2008, 2010) also confirmed an increase of apple yield in Po-Bicarb treatments compared with untreated plots. In addition, Slatnar et al. (2012) reported an increase in fruit mass and of some phenolic compounds of fruit for ‘Braeburn’ in Po-Bicarb treatments compared with untreated plots. Our study provided new data that yield significantly increased in the treatments of Po-Carb or Po-Bicarb combined with Wett-S in all years for both cultivars compared with untreated plots when pruning treatments and a whole-field sanitation practice were also performed. However, pruning alone (i.e., in the untreated plots) was not able to significantly increase yield because, in these cases, disease levels were high. As soon as fungicide treatments reduced the disease level, the yield-increasing potential of pruning could be visible; for example, pruning promoted spray penetration and foliage drying inside the tree canopy (Holb 2005). Pruning also influences vegetative versus generative balance of the tree but, in our study, only a weak pruning was performed because the upper third of the 1-year-old shoots was removed, which caused negligible effect on this tree balance.

In summary, none of the potassium carbonate treatments were as effective as the conventional fungicide treatments but they significantly reduced apple scab and powdery mildew under pruning treatments compared with untreated plots. These treatments also caused low phytotoxicity, and they were able to increase fruit yield to some extent compared with the untreated plots. Overall, both carbonate compounds (under 1% dosage) in combination with a reduced use of Wett-S can be suggested for practical use because they provided low phytotoxicity risk and good powdery mildew control as well as increased yield in combined pruning treatments. Because the use of copper and Lime-S is restricted or banned in several countries for plant protection, Po-Carb or Po-Bicarb in combination with Wett-S and integration with pruning and whole-orchard sanitation treatments can be an environmentally safe and viable option for both scab and powdery mildew control in organic apple production. Our results clearly implied that an improved integrated control strategy is essential for scab and powdery mildew control in organic apple production. Other control methods (e.g., more effective biocontrol agents and inducers of systemic acquired resistance) in combination with sanitation, cultivar selection, or fungicide applications may provide even more adequate disease control in organic apple production.

Table 8. Yield of Idared and Jonathan apple in nine fungicide treatments and two pruning treatments at mid-June in an organic apple orchard (Eperjeske, Hungary, 2011 to 2014)

	Yield of apple (kg tree^{-1})[x]										
	2011		2012		2013		2014		All years		
Pruning, treatment[y]	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Idared	Jonathan	Overall[z]
Unpruned											
Po-Bicarb	14.6 ab	12.8 a	12.4 ab	10.4 a	18.4 ab	16.1 ab	12.7 ab	11.5 ab	14.5 ab	12.7 ab	13.6 ab
Po-Carb	15.8 ab	13.7 a	13.4 ab	11.3 a	17.3 ab	15.2 ab	11.4 ab	12.4 ab	14.5 ab	13.2 ab	13.8 ab
Wett-S	15.9 ab	13.9 a	14.2 ab	11.7 a	19.2 ab	16.8 ab	12.6 ab	12.1 ab	15.5 ab	13.6 ab	14.5 ab
Lime-S	17.5 ab	15.5 a	15.5 ab	12.8 a	19.1 ab	17.2 ab	14.1 b	13.5 b	16.5 ab	14.7 ab	15.6 ab
Po-Bicarb + Wett-S	17.7 ab	15.6 a	16.5 b	13.7 a	19.3 b	16.9 ab	14.6 b	13.2 ab	17.0 b	14.9 ab	15.9 ab
Po-Carb + Wett-S	18.1 b	15.9 a	14.7 ab	12.6 a	21.3 b	18.7 bc	14.3 b	13.5 b	17.1 b	15.2 b	16.1 b
Conv-Difen	26.7 c	23.4 b	22.7 c	20.7 b	28.2 c	24.8 cd	25.8 c	24.1 c	25.8 c	23.3 c	24.5 c
Conv-Dithian	25.3 c	22.2 b	24.3 c	20.8 b	30.4 c	26.7 d	23.7 c	22.1 c	25.9 c	22.9 c	24.4 c
Untreated	12.2 a	10.7 a	10.3 a	8.9 a	13.1 a	11.9 a	8.7 a	7.6 a	11.1 a	9.8 a	10.4 a
$LSD_{0.05}$	5.8	5.4	6.1	4.9	6.1	6.1	5.3	5.6	5.8	5.3	5.6
Pruned											
Po-Bicarb	16.6 ab	13.4 a	13.3 ab	14.3 abc	18.1 b	18.0 b	15.2 ab	12.4 ab	15.8 ab	14.5 ab	15.2 ab
Po-Carb	18.6 ab	16.7 ab	14.2 ab	14.5 abc	17.2 ab	17.6 ab	13.6 ab	12.1 ab	15.9 ab	15.2 ab	15.6 ab
Wett-S	18.0 ab	17.6 ab	15.2 ab	15.7 bc	19.1 b	19.3 bc	14.9 ab	12.3 ab	16.8 ab	16.2 ab	16.5 ab
Lime-S	20.1 ab	19.2 b	16.8 bc	12.4 ab	19.8 bc	19.3 bc	16.8 b	15.2 b	18.4 b	16.5 b	17.4 b
Po-Bicarb + Wett-S	20.4 b	19.3 b	17.2 bc	16.7 cd	19.9 bc	19.1 b	17.4 b	15.8 b	18.7 b	17.7 b	18.2 b
Po-Carb + Wett-S	20.9 b	19.4 b	15.5 bc	15.8 bc	22.0 bc	22.3 bcd	17.2 b	16.1 b	18.9 b	18.4 b	18.6 b
Conv-Difen	30.0 c	26.5 c	20.4 cd	20.1 de	24.7 cd	24.3 cd	30.1 c	26.5 c	26.3 c	24.4 c	25.3 c
Conv-Dithian	30.2 c	27.3 c	22.5 d	21.1 e	28.2 d	25.4 d	28.4 c	23.4 c	27.3 c	24.3 c	25.8 c
Untreated	14.2 a	12.7 a	11.4 a	10.6 a	12.6 a	12.5 a	10.3 a	8.5 a	12.1 a	11.1 a	11.6 a
$LSD_{0.05}$	5.9	5.3	4.0	4.2	5.3	5.1	5.5	5.7	5.3	5.1	5.2
Overall unpruned	18.2 a	15.9 a	15.9	13.6	20.7	18.3	15.3 a	14.4	17.5	15.6	16.6
Overall pruned	21.0 b	19.1 b	16.3	15.7	20.2	19.7	18.2 b	15.8	18.9	17.6	18.3
$LSD_{0.05}$	2.7	3.1	ns	ns	ns	ns	2.8	ns	ns	ns	ns

[x] Values followed by the same letter are not significantly different according to least significant difference (LSD) test ($LSD_{0.05}$ at $P = 0.05$ level); ns = nonsignificant; therefore, letters are not applied here for showing significant differences.

[y] Treatment codes: Po-Bicarb = potassium bicarbonate, $KHCO_3$ (Vitisan); Po-Carb = potassium monocarbonate, K_2CO_3 (Omni Protect); Wett-S = wettable sulfur (Kumulus S); Conv-Difen = conventional systemic fungicide control, difenoconazole (Score 250 EC); and Conv-Dithian = conventional contact fungicide control, dithianon, (Delan 750 SC). For potassium carbonate treatments, application rates below 1% were used according to Tamm et al. (2006), Kelderer et al. (2008), and personal experience in order to reduce phytotoxicity.

[z] Overall year and cultivar.

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