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Evaluating primary scab control in organic apple production

Bewertung von Verfahren zur Kontrolle von Frühschorf im organischen Apfelanbau

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Summary

Effect of spray schemes with sulphur and lime sulphur either alone or in various combinations with other fungicidal products were evaluated for phytotoxicity and scab control over three years in a search for better primary scab control in organically maintained apple orchards. The results show that sprays of 0.5 % wettable sulphur might be applied successfully in a 5–7-day protectant schedule under low disease pressure during primary infection season. During the same period, poor efficacy of 0.5 % wettable sulphur sprays was observed under heavy spring disease pressure. Sprays of 0.75 % wettable sulphur combined with 0.05 % or 0.1 % copper hydroxide, or sprays of 0.2–0.5 % wettable sulphur combined with 2 % lime sulphur gave better control of primary scab. However, the effectiveness of these combined treatments was less than that of conventional reference fungicides and their phytotoxicity was higher compared to treatments with wettable sulphur alone or with conventional reference fungicides. Results indicate that lime sulphur in combination with elementary sulphur might replace copper fungicides with respect to its efficacy against scab. Evaluated schedules with approved fungicidal products used in organic growing are presented and the practical implications of the results are discussed.

Zusammenfassung

Spritzfolgen mit Schwefel und Schwefelkalk, allein oder in Kombination mit anderen fungiziden Präparaten wurden im Hinblick auf Phytotoxizität und Wirksamkeit gegen Apfelschorf über drei Jahre untersucht. Dabei ging es um die Verbesserung der Bekämpfung von Primär-Schorf im organischen Apfelanbau. Spritzungen mit 0,5 %-igem Netzschwefel können bei 5–7-tägiger vorbeugender Spritzfolge erfolgreich sein unter Bedingungen mit geringem Befallsdruck in der Phase der Primärinfektionen. Die gleiche Anwendung zeigte im Frühjahr nur geringe Wirksamkeit bei hohem Befallsdruck. Spritzflüssigkeiten mit 0,75 % Netzschwefel und 0,05 % bzw. 0,1 % Kupferhydroxid oder 0,2–0,5 % Netzschwefel in Mischung mit 2 % Schwefelkalk zeigten eine bessere Wirksamkeit gegen Frühschorf. Allerdings war die Wirksamkeit der kombinierten Behandlungen geringer als bei konventionellen, als Referenz verwendeten Fungiziden. Außerdem war die Phytotoxizität höher als bei Netzschwefel allein oder in Kombination mit Referenz-Fungiziden. Die Ergebnisse lassen den Schluß zu, dass Schwefelkalk in Kombination mit elementarem Schwefel Kupfer-Fungizide im Hinblick auf die Wirkung gegen Schorf ersetzen kann. Bewertete Spritzfolgen mit erprobten und im organischen Anbau angewendeten fungiziden Präparaten werden dargestellt. Hinweise zur Umsetzung der Ergebnisse in der Praxis werden diskutiert.

Introduction

Apple scab, caused by the fungus *Venturia inaequalis* (Cke.) Winter, occurs wherever apples are grown (BIGGS 1990). Spring weather often provides suitable conditions for the development of severe scab epidemics in The Netherlands. Therefore, frequent fungicide applications are needed to control apple scab. In general, control measures are based largely on protective fungicide sprays timed according to the developmental stage of the trees and ascospore maturity and release from overwintering leaves (MACHARDY and JEGER 1982, SZKOLNIK 1969). These treatments are supplemented by curative sprays applied after weather conditions for infection have occurred (MACHARDY and GADOURY 1989, PENROSE 1989). As consumers increasingly demand apples free of chemical residues and as environmental considerations become more important, there is increasing emphasis on reducing the use of pesticides in apple production. This has generated a great deal of interest in organic apple production. However, the use of synthetic products including fungicides, which form the basic elements of conventional crop protection, is prohibited in organic fruit production. Only stable manure, compost, soluble rock powders, sulphur and copper compounds, fungicidal and insecticidal soaps, botanical insecticides, traps and biological control methods are permitted in organic growing systems (IFOAM 1989). However, control of diseases, including apple scab, is more difficult to achieve with organic alternatives than conventional fungicides. Approved fungicidal products, based upon sulphur and copper, are less effective and often more phytotoxic than modern synthetic fungicides (ELLIS et al. 1991, MACHARDY 1996). Elementary sulphur, lime sulphur and copper were used commonly in the early 1900s (HAMILTON 1931, MACHARDY 1996), but the efficacy of these fungicides was not evaluated in season-long disease management. Moreover, due to the lack of interest in

the inorganic fungicides over the past 30 to 35 years, these fungicides were not extensively tested in modern production systems. In most organic orchards, scab is controlled by using copper- and sulphur-containing fungicides. In a common Dutch scheme, one to three sprays of copper are applied in the early spring followed by wettable sulphur sprays during wet periods until harvest. Such a schedule often results in severe scab development by harvest, indicating a more effective scab control program is needed, during periods of ascospore release. The Netherlands Government banned copper fungicides from the year 2000. Copper is one of the effective compounds for disease control in organic production. It seems to be a trend that copper will be forbidden in other European countries in organic growing because of environmental reasons. Therefore, research should be aimed at searching for alternatives. In a recent study, ELLIS et al. (1998) demonstrated that in other areas there is also a need to improve apple scab control and reduce phytotoxicity of products applied in organic apple production.

The work reported here aimed at evaluating the control of primary apple scab in organically maintained modern production systems. Our specific objective was to evaluate the phytotoxicity and the effectiveness of sulphur and lime sulphur applied either alone or in various combinations with other products during the period of ascospore infections.

Materials and Methods

Orchards, equipment and general recording

Three trials were conducted, one in 1997 at Geldermalsen and two in 1998 and 1999 at Randwijk in The Netherlands. The Geldermalsen site was planted in 1986 with single rows of apple cultivar (cv.) 'Vista Bella' with the pollinizer cv. 'Lombarts Calville' at a spacing of 3.5x1.25 m. The Randwijk site consisted a block wherein two rows of cv. 'Jonagold' alternated with two rows of cv. 'Schone van Boskoop'. This site was planted in 1996 at planting distance of 3x1.25 m. The eighth tree in each row was a pollinizer cv. 'Delcorf'. Trees were grown according to the Dutch organic guidelines derived from IFOAM standards (IFOAM 1989, 1998). The cultivars were on M.9 rootstock and pruned as slender spindles in both locations.

All sprays were applied with a handheld spray gun (manufacturer EMPASS, Huneschans 18 3905 XL Veenendaal, The Netherlands) with a ceramic hollow cone at 1.1–1.2 MPa with a volume of 1000 l ha^{-1}.

Potential infection periods, based on the criteria of MILLS and LA PLANTE (1951), were recorded at each site with a METY computer-based weather recorder and a scab warning system (BOSHUIZEN and VERHEYDEN 1994) from green tip through to harvest. Tree growth stages were recorded throughout the ascospore infection period according to Fleckinger-growth stage scale (EPPO/OEEP 1984). Observations were made on cv. 'Vista Bella' at Geldermalsen and on cv. 'Jonagold' at Randwijk. Both cultivars are susceptible to apple scab.

Treatments

One trial per year was conducted from 1997 through 1999. Treatments were in randomized blocks with five replicates. Each block consisted of seven trees but observations were only made on the five middle trees of each plot. Single trees were used as observation units. According to the results obtained, the treatments were adjusted each year in the search for better spray combinations with low phytotoxicity. Tested products are summarized in Table 1.

Geldermalsen, 1997. Treatment spray schedules were:
1. untreated control;
2. nine sprays of captan at 1.5 Kg ha^{-1} (0.15 %) as a conventional reference;
3. nine sprays of wettable sulphur at 5 Kg ha^{-1} (0.5 %);

Table 1. Applied products against apple scab.
Gegen Apfelschorf eingesetzte Präparate

Common name	Active ingredient	Trade name	Manufacturer	Country	Years applied		
					1997	1998	1999
wettable sulphur	elementary sulphur, 80 %	Kumulus S	BASF Nederland BV	The Netherlands	x	x	
wettable sulphur	elementary sulphur, 80 %	Thiovit S	Novartis Agro Benelux BV	The Netherlands			x
liquid sulphur	elementary sulphur, 70	Helisoufre S	Samabiol AG	France			x
lime sulphur	calcium polysulphides, 23.5 %	Kalkzwavel	Polisenio	Italy	x	x	x
copper hydroxide	copper hydroxide, 50 %	Fungaran-OH	Aseptafabriek BV	The Netherlands	x	x	x
mineral oil	mineral oil, 800 g l^{-1}	Luxan olie-H	Luxan BV	The Netherlands			x
stone flour	acid clay minerals, 50 % + aluminumligninsulphate, 5 % + *Equisetum* extract 1 %	Myco-Sin	Andermatt Biocontrol AG	Switzerland			x
captan	captan, 80 %	Captosan 80WG	Novartis Agro Benelux BV	The Netherlands	x		
dithianon	dithianon, 750 g l^{-1}	Delan Flowable	Cyanamid Agro BV	The Netherlands		x	
pyrimethanil	pyrimethanil, 400 g l^{-1}	Scala	AgrEvo Nederland BV	The Netherlands			

4. nine sprays of wettable sulphur at 5 Kg ha^{-1} (0.5 %) combined with copper hydroxide at 1 Kg ha^{-1} (0.1 %);
5. three sprays of lime sulphur at 20 l ha^{-1} (2 %) followed by six sprays of wettable sulphur at 5 Kg ha^{-1} (0.5 %).

All schedules began with one 0.3 % copper hydroxide application on 28 March. The sprays in all treatments were applied at weekly intervals on 10, 17, 24 April, 1, 7, 13, 21, 28 May, and 6 June. From the middle of June, all treatment schedules changed to 0.5 % wettable sulphur at 10–14 day intervals (10, 28 June, 10, and 24 July).

Leaf phytotoxicity and leaf scab were recorded on 15 extension shoots per sampled tree on 2 August. Observations were made on 10 mature leaves per shoot. All fruits were harvested on 5 August and fruit phytotoxicity and fruit scab were assessed on all fruits per plot on the same date. Scab incidence was assessed on leaves and fruits using the scale based on that of CROXALL et al., (1952a, 1952b). Leaf phytotoxicity was assessed on the whole leaf lamina (EPPO/OEEP 1997). Assessments were rated according to the scale: 0 = no damage; 1 = leaf size 60–80 % of normal size, no leaf necroses; 2 = leaf size less than 60 % of normal size, no leaf necroses; 3 = leaf less than 60 % of normal size and with brown margins (less than 3 % leaf necroses); 4 = leaf less than 60 % of normal size and 3–6 % leaf necroses; and 5 = bumpy, small leaf and more than 6 % leaf necroses. Fruit russetting was recorded according to EPPO/OEEP (1997) standards, based on a scale of 1 to 4: class 1 = no russet; class 2 = 1–11 %; class 3 = 12–33 %; and class 4 = > 33 % russetted fruit surface area. To quantify fruit russetting, an index was calculated according to the following equation:

$$RI\ (\%) = (N_{class1} / N_t) \bullet 0 + (N_{class2} / N_t) \bullet 6 + (N_{class3} / N_t) \bullet 22.5 + (N_{class4} / N_t) \bullet 66.5,$$

in which RI (%) = fruit russetting index (average percentage of fruit surface russetted); N_{class1}, N_{class2}, N_{class3}, and N_{class4} represent the number of fruits in each class of russetting; N_t = total number of fruits. Numbers (0, 6, 22.5, 66.5) in the equation represent the percentage of russetted fruit expressed as a mean of the lower and upper boundary of class 1, class 2, class 3, and class 4, respectively. The lower and upper boundaries of class 1 are 0 and the upper boundary of class 4 is 100.

Randwijk, 1998. Based on the results of 1997, the treatment schedules were modified as follows: a) wettable sulphur was used at a higher dosage; b) wettable sulphur was applied together with mineral oil or with copper hydroxide in various combinations; c) lime sulphur was applied either alone or combined with mineral oil. Although mineral oil is used against insects in organic orchards and not against apple scab, it was added to the treatments because of its potential phytotoxic effects according to grower experience. Treatment schedules were:

1. untreated control;
2. five sprays of dithianon at 0.5 l ha^{-1} (0.05 %) as a conventional reference;
3. five sprays of wettable sulphur at 7.5 kg ha^{-1} (0.75 %);
4. five sprays of wettable sulphur at 7.5 kg ha^{-1} (0.75 %) plus mineral oil at 30 l ha^{-1} (3 %);
5. five sprays of wettable sulphur at 7.5 kg ha^{-1} (0.75 %) combined with copper hydroxide at 0.5 kg ha^{-1} (0.05 %);
6. as treatment (5) but applied with copper hydroxide at 1 kg ha^{-1} (0.1 %);
7. as treatment (6) plus mineral oil at 30 l ha^{-1} (3 %);
8. five sprays of lime sulphur at 20 l ha^{-1} (2 %);
9. as treatment (8) plus mineral oil at 30 l ha^{-1} (3 %).

All schedules started with a 0.3 % copper hydroxide application on 25 March. The sprays in all treatments were applied at weekly intervals on 1, 6, 14, 21, and 28 April 1998. Mineral oil was used once on 6 April, separately from the fungicides in treatment 4, 7, and 9. Treatments 3 to 9 were sprayed with 0.45 % wettable sulphur from beginning of May till middle of June at weekly intervals on 4, 11, 19, 27 May, 4, and 12 June. The applications were not changed in treatment 1 and 2 during this period. All treatments were treated with 0.45 % wettable sulphur from middle of June till harvest at 10–14 day intervals (24 June, 6, 20, 31 July, 10, 19, 29 August, 12, and 24 September). Leaf scab and leaf phytotoxicity were recorded on 60 leaf clusters per tree on 13 and 20 May, respectively. Observations were made on 5–7 newly unfolded leaves per sampled cluster. Fruit phytotoxicity and fruit scab were assessed on all fruits per plot at harvest on 10 October, when all fruits were picked and weighed. Scab incidences and phytotoxicity values were recorded and calculated as described for Geldermalsen in 1997.

Randwijk, 1999. Treatment schedules were again modified based on the results of 1998 as follows: a) treatments applied with copper hydroxide were restricted because of the prohibition of copper fungicides in The Netherlands from the year 2000; b) replacement of copper hydroxide with stone flour or lime sulphur was evaluated; c) liquid sulphur was tested alone; and d) dosages of wettable and liquid sulphur were modified according to the developmental stage of the trees and temperature. Treatment schedules were:

1. untreated control;
2. six sprays of pyrimethanil at 0.75 l ha^{-1} (0.075 %) as a conventional reference;
3. eleven sprays of wettable sulphur at 2–4 kg ha^{-1} (0.2–0.4 %);
4. eleven sprays of wettable sulphur at 4–8 kg ha^{-1} (0.4–0.8 %);
5. as treatment (3) applied with copper hydroxide at 0.5 kg ha^{-1} (0.05 %);
6. as treatment (3) applied with lime sulphur at 20 l ha^{-1} (2 %);
7. as treatment (3) applied with stone flour at 8 kg ha^{-1} (0.8 %);
8. eleven sprays of liquid sulphur at 3–6 l ha^{-1} (0.2–0.6 %).

The dosage of sulphur was dependent on temperature, growth and predicted danger of infection. When temperature was lower than 15 °C or risk of infection was low, then the lower dosage was applied. During flowering, the dosage was lowered to 0.2 to 0.3 %.

The sprays in all treatments were applied on 2, 8, 12, 15, 20, 23, 29 April, 7, 12, 19, and 27 May 1999. From the beginning of June, all treatment schedules were changed to 0.45 % wettable sulphur at 10–14 day intervals (2, 13, 25 June, 8, 20, 31 July, 10, 21 August, 3, and 17 September). Leaf phytotoxicity and leaf scab were recorded on 60 leaf clusters per tree on 11 May. Observations were made on 5–7 newly unfolded leaves per each cluster. Leaf scab was also recorded on 30 shoots

Table 2. Dates of infection periods from the beginning of April until the middle of June as calculated by METY computer-based scab warning system and tree growth stages from green tip (C3) to fruit swelling (J) at Geldermalsen and Randwijk, The Netherlands, 1997–1999.
Termine der Schorfinfektionsperioden zwischen Anfang April und Mitte Juni, berechnet mit dem METY computer-basierten Schorf-Warn-Modell in den Wachstumsstadien zwischen „grüner Spitze" (C3) und zweitem Fruchtfall (J). Standort: Geldermalsen und Randwijk, Niederlande, 1997–1999.

Location and season	Dates of infection periods (day/month)				Dates of tree growth stages		
Geldermalsen	10 April (L)[y]	1 May (L)	10 May (M)	16 May (H)	18 March (C3)[z]	28 March (D2)	16 April (E2)
1997	21 May (H)	24 May (H)	10 June (L)		25 April (F2)	8 May (I)	22 May (J)
Randwijk	3 April (M)	5 April (H)	7 April (L)	12 April (H)	20 March (C3)	3 April (D2)	19 April (E2)
1998	21 April (H)	5 May (H)	7 May (L)	11 May (H)	5 May (F2)	18 May (I)	5 June (J)
	13 May (H)	20 May (H)	28 May (H)	3 June (H)			
	5 June (H)	6 June (H)	7 June (H)	11 June (H)			
	14 June (M)						
Randwijk	1 April (H)	5 April (H)	9 April (M)	13 April (H)	21 March (C3)	4 April (D2)	17 April (E2)
1999	20 April (M)	23 April (H)	27 April (L)	5 May (H)	2 May (F2)	14 May (I)	3 June (J)
	24 May (H)	28 May (M)	3 June (M)	9 June (H)			
	11 June (M)	14 June (H)					

[y] The severity of infection periods as calculated by METY are in parentheses: L, low; M, moderate; H, heavy.
[z] Tree growth stages according to Fleckinger-growth stage scale (EPPO/OEEP, 1984) are in parentheses: C3, green tip; D2, early tight cluster; E2, tight cluster; F2, full bloom; I, fruit setting; J, fruit swelling.

per tree on 3 July. Observations were made on 10 older leaves per shoot. Fruits were harvested on 5 October. Scab incidence and phytotoxicity values as well as yield and fruit weight were recorded and calculated as described for Geldermalsen in 1997 and for Randwijk in 1998, respectively.

Statistical methods

All data were subjected to analysis of variance (ANOVA) using the Genstat 5 Release 4.1 statistical package (GENSTAT 5 COMMITTEE 1997). The incidence values of apple scab were transformed to angular (Y=arcsine $[\%]^{1/2}$) to correct normality before analysis. Significant F-tests ($P < 0.05$) were followed by a Least Significance Difference (LSD)-test for pair wise comparison of treatment means using $LSD_{0.05}$ values.

Results

Mills infection periods

At Randwijk, 17 and 14 infection periods were recorded during the 10–11 weeks from the beginning of April till the middle of June in 1998, and 1999, respectively (Table 2). These periods coincided with the tree growth stages early tight cluster (D1) to fruit swelling (J), when infections are caused by ascospores (Table 2). In Geldermalsen, only 7 infection periods occurred caused by ascospores during the same period. A total of 20, 48, and 44, infection periods were recorded from green tip through to harvest in 1997, 1998, and 1999, respectively. The spring of 1997 was relatively dry while springs of 1998 and 1999 were wet to very wet. In addition, disease pressure was much more severe at Randwijk in both years. This was due to the presence of untreated plots year after year in this orchard before the experiments started.

Scab incidence

The incidence of scab was considerably higher on cv. 'Jonagold' at Randwijk than on cv. 'Vista Bella' at Geldermalsen (Tables 3, 4 and 5).

All treatments significantly decreased disease incidence on leaves and fruits compared to untreated plots (Tables 3, 4 and 5) except for treatments with 0.2–0.4% wettable sulphur plus 0.8% stone flour (Table 5). Wettable sulphur applied alone resulted in good scab control at Geldermalsen on cv. 'Vista Bella' in 1997 (Table 3), but wettable or liquid sulphur treatments applied alone were generally less effective at Randwijk in both years (Tables 4 and 5). Combinations of products gave better results at Randwijk. Treatments with wettable sulphur plus copper hydroxide or lime sulphur resulted in scab free 'Vista Bella' fruits similar to the conventional reference sprayed with captan (Table 3). These combinations significantly reduced the incidence of scab on leaves and fruits compared to unsprayed plots at Randwijk (Tables 4 and 5). Wettable sulphur at 0.5% or 0.75% in combination with copper gave relatively good scab control on fruit in 1997 and 1998 (Tables 3 and 4). In 1999, however, the combined treatments with half a dosage of wettable sulphur resulted in a high level of scab both leaves and fruits (Table 5). In short, 0.5% wettable sulphur in combination with 0.1% copper hydroxide or 2% lime sulphur resulted in the best scab control on cv. 'Vista Bella' (Table 3) and 0.75% wettable sulphur applied with 0.1% or 0.05% copper hydroxide gave the lowest incidences of fruit scab on cv. 'Jonagold' (Table 4).

Table 3. Effect of treatments on incidence of apple scab, phytotoxicity and harvested fruits for apple cultivar 'Vista Bella', at Geldermalsen, The Netherlands.
Wirkung der Behandlungen auf: Häufigkeit von Apfelschorf, Phytotoxiziät und Fruchtertrag zum Erntezeitpunkt bei der Apfelsorte 'Vista Bella', in Geldermalsen, Niederlande.

Treatment and dosage[s]	Scab incidence (%)[t]		Phytotoxicity		Yield per plot
	Leaf (2 August)	Fruit (5 August)	Leaf[v] (2 August)	Fruit[w] (5 August)	Fruit number (5 August)
Untreated control	23.6 b[u]	3.3 b	0.0 a	4.3 a	103.3 a
C (0.15%)	0.8 a	0.0 a	0.0 a	4.7 a	154.7 b
WS (0.5%)	2.5 a	0.1 a	0.1 a	4.8 a	132.8 ab
WS (0.5%) + CH (0.1%)	0.8 a	0.0 a	3.5 c	7.8 b	132.2 ab
WS (0.5%) + LS (2%)	1.7 a	0.0 a	2.8 b	5.3 a	117.5 ab
F-test[x]	***	**	***	***	*
SED (df = 20)[y]	–[z]	–	0.14	0.67	21.58
$LSD_{0.05}$	–	–	0.31	1.41	45.99

[s] Codes of treatments are: C = captan, WS = wettable sulphur, CH = copper hydroxide, LS = lime sulphur. Dosages are in parentheses.

[t] Scab incidence data shown are back-transformed means from arcsine [%]1/2 values.

[u] Values within columns followed by different letters are significantly different.

[v] Leaf phytotoxicity assessment rated on a scale of 0 to 5: 0 = no damage; 1 = leaf size 60–80% of normal size, no leaf necroses; 2 = leaf size less than 60% of normal size, no leaf necroses; 3 = leaf less than 60% of normal size and with brown margins (less than 3% leaf necroses); 4 = leaf less than 60% of normal size and 3–6% leaf necroses; and 5 = bumpy, small leaf and more than 6% leaf necroses.

[w] Fruit russetting index (RI) rated on a scale of 1 to 4: 1 class 1 = no russet; class 2 = 1–11%; class 3 = 12–33%; and class 4 = > 33% russetted fruit surface area.

[x] n. s. not significant, *,**,*** significant at $p < 0.05, 0.01, 0.001$.

[y] SED = standard errors of differences of mean values; df = degrees of freedom.

[z] Because of the back-transformation on scab incidence data set, no LSD and SED values are available.

Table 4. Effect of treatments on incidence of apple scab, phytotoxicity and harvested fruits for apple cultivar 'Jonagold', at Randwijk, The Netherlands.
Wirkung der Behandlungen auf: Häufigkeit von Apfelschorf, Phytotoxiziät und Fruchtertrag zum Erntezeitpunkt (10. Oktober 1998) bei der Apfelsorte 'Jonagold', in Randwijk, Niederlande.

Treatment and dosages	Scab incidence (%)[t]		Phytotoxicity		Yield per plot		
	Leaf (13 May)	Fruit (10 October)	Leaf[v] (20 May)	Fruit[w] (10 October)	Fruit number (10 October)	(kg per plot) (10 October)	Fruit weight (g) (10 October)
Untreated control	42.5 d[u]	89.9 e	0.0 a	4.9 a	69.0 a	13.6	195.9 bc
D (0.05%)	7.7 bc	25.9 bc	0.0 a	4.3 a	112.8 b	21.9	188.5 abc
WS (0.75%)	12.9 c	44.1 d	0.7 b	4.7 a	98.4 ab	17.5	177.1 ab
WS (0.75%) + MO (3%)	3.6 ab	19.7 ab	–[zz]	4.8 a	98.8 ab	19.0	189.4 abc
WS (0.75%) + CH (0.05%)	1.6 a	10.7 a	–[zz]	5.6 a	71.2 a	14.6	201.3 c
WS (0.75%) + CH (0.1%)	0.5 a	8.0 a	–[zz]	6.2 ab	84.0 ab	17.8	199.6 c
WS (0.75%) + CH (0.1%) + MO (3%)	1.1 a	12.7 ab	2.9 c	8.1 b	92.6 ab	17.8	193.9 bc
LS (2%)	8.9 bc	47.8 d	2.6 c	4.5 a	80.6 ab	15.1	187.4 abc
LS (2%) + MO (3%)	10.9 c	35.6 cd	3.1 c	5.2 a	83.0 ab	15.0	173.9 a
F-test[x]	***	***	***	**	*	n. s.	*
SED (df = 32)[y]	-[z]	–	0.37	0.95	16.49		9.76
$LSD_{0.05}$	–	–	0.75	1.98	33.59		19.89

[s] Codes of treatments are: D = dithianon, WS = wettable sulphur, MO = mineral oil, CH = copper hydroxide, LS = lime sulphur. Dosages are in parentheses.

[t, u, v, w, x, y] and [z] for explanation, see Table 3.

[zz] No observations were made.

Table 5. Effect of treatments on incidence of apple scab, phytotoxicity and harvested fruits for apple cultivar 'Jonagold', at Randwijk, The Netherlands.
Wirkung der Behandlungen auf: Häufigkeit von Apfelschorf, Phytotoxiziät und Fruchtertrag zum Erntezeitpunkt bei der Apfelsorte 'Jonagold', in Randwijk, Niederlande.

Treatment and dosages	Scab incidence (%)[t]			Phytotoxicity		Yield per plot		
	Cluster leaf (11 May)	Leaf (3 July)	Fruit (5 October)	Leaf[v] (3 July)	Fruit[w] (5 October)	Fruit number (5 October)	(kg per plot) (5 October)	Fruit weight (g) (5 October)
Untreated control	42.5 e[u]	99.5 d	99.0 e	0.0 a	4.4 ab	208.4 a	34.0 a	164.0 a
P (0.075%)	0.1 a	14.3 a	15.6 a	0.0 a	4.0 a	327.4 c	68.6 c	209.0 b
WS (0.2–0.4%)	12.1 cd	68.9 b	75.9 cd	0.4 ab	4.5 ab	312.4 c	62.5 bc	202.7 b
WS (0.4–0.8%)	17.4 d	67.4 bc	66.9 bc	0.7 b	4.5 ab	257.4 abc	52.9 b	206.2b
WS (0.2–0.4%) + CH (0.05%)	5.0 abc	61.2 b	50.5 b	0.7 b	4.95 bcd	295.8 bc	58.6 bc	197.3 b
WS (0.2–0.4%) + LS (2%)	3.1 abc	54.5 b	60.4 bc	2.6 c	4.8 bc	308.8 c	62.2 bc	201.6 b
WS (0.2–0.4%) + SF (0.8%)	17.5 d	83.1 c	89.5 de	1.0 b	5.1 cd	237.6 ab	47.5 ab	201.8 b
LQS (0.2–0.6%)	9.5 bcd	67.2 bc	65.2 bc	3.9 d	5.5 d	235.8 ab	49.7 b	210.5 b
F-test[x]	***	***	***	***	***	*	**	*
SED (df = 28)[y]	–[z]	–	–	0.36	0.27	34.45	7.54	12.02
$LSD_{0.05}$	–	–	–	0.71	0.57	70.57	15.46	24.61

[s] Codes of treatments are: P = pyrimethanil, WS = wettable sulphur, CH = copper hydroxide, LS = lime sulphur, SF = stone flour, LQS = liquid sulphur. Dosages are in parentheses.
[t, u, v, w, x, y] and [z] for explanation, see Table 3.

Phytotoxicity values

Combinations of wettable sulphur with copper hydroxide, lime sulphur, stone flour, and lime sulphur with mineral oil as well as lime sulphur or liquid sulphur alone affected leaves negatively in all locations (Tables 3, 4 and 5). Fruit russet was increased by 0.1% copper hydroxide, or 0.8% stone flour, or 0.2–0.6% liquid sulphur (Tables 3, 4 and 5). The most effective treatments against scab caused significantly higher leaf damage compared to untreated control, but had only a small effect on fruit russetting (Table 3 and 4) except for the sulphur/copper hydroxide combination at Geldermalsen (Table 3) and treatments applied with sulphur plus copper hydroxide plus mineral oil at Randwijk (Table 4). Wettable sulphur applied alone had only a slight phytotoxic effect. Only wettable sulphur in concentrations of 0.75% and 0.8% caused slight leaf phytotoxicity on cv. 'Jonagold', but fruit russet did not differ significantly from untreated plots (Tables 4 and 5). However, liquid sulphur was phytotoxic both to leaves and fruits when compared with untreated plots (Table 5). Mineral oil in schedules with copper hydroxide or lime sulphur gave considerably better scab control when compared with unsprayed treatment but these treatments were highly phytotoxic (Table 4).

Yield responses

In 1997 and 1998, only the reference treatments with captan or dithianon resulted in significantly higher yields in both cultivars compared to the untreated control (Tables 3 and 4). In 1999, almost all treatments significantly increased fruit yield on cv. 'Jonagold', except for the treatments with 0.2–0.4% wettable sulphur plus 0.8% stone flour and 0.2–0.6% liquid sulphur alone (Table 5).

Discussion

The aim of this study was to evaluate primary scab control in organic apple orchards. The results presented here clearly demonstrate that it is not feasible to successfully grow scab-susceptible apple cultivars without the use of fungicide under Dutch conditions. Further, it is clear that in both sites, conventional standard fungicides (captan, dithianon, and pyrimethanil) gave more effective scab control than products approved for organic production.

In most Dutch organic orchards, the average disease pressure is in between that encountered in Geldermalsen and Randwijk. This should be taken into account when interpreting the results of described experiments for practical purposes.

In Geldermalsen, all products gave good scab control on cv. 'Vista Bella' under low disease pressure and a limited number of infection periods during the ascospore season. Furthermore, it was also noted that 0.5% wettable sulphur applied alone showed good protective activity from mid June to harvest. In addition, no phytotoxicity effects were observed on harvested fruits where wettable sulphur was used. These results indicate that wettable sulphur might be applied successfully on a 5–7-day protectant schedule depending on the rate of leaf development during the period of ascospore infections, and that it can even prevent infections on a 10–14 day schedule during the summer months. This conclusion is in agreement with the studies of ELLIS et al. (1991,1994) under Ohio conditions.

Compared to Geldermalsen, the Randwijk orchard with its heavy disease pressure and more scab infection periods gave different results. Here, wettable sulphur applied at weekly intervals was not sufficiently effective against scab during the ascospore season (Tables 4 and 5). It is concluded that the relatively weak protective activity and the lack of curative activity of sulphur can

not give effeftive scab control under high inoculum pressure favoured by scab conducive weather. Similar conclusions have been made by others (ELLIS et al. 1994, 1998, LEWIS and HICKEY 1972). This indicates that in exceptionally wet years, wettable sulphur is risky to use. In accordance with our results, other researchers have reported that, lime sulphur and copper were more effective during the ascospore season than elementary sulphur (COOLEY et al. 1991, HAMILTON 1931). However, both fungicides were phytotoxic to leaves and fruits in our experiments. Copper fungicides are commonly used in organic apple orchards due to their good protective activity, whether applied alone or in various combinations with sulphur. In Randwijk, wettable sulphur in combination with copper resulted in relatively good scab control. Wettable sulphur at 0.75% applied with 0.05% or 0.1% copper hydroxide seemed to be the best scab control treatment for cv. 'Jonagold' (Table 4). However, the prohibition of copper fungicides in the Netherlands and possibly other European countries in the future stresses the need for other products in organic production. One of the possibilities is likely to be lime sulphur. In the past, HAMILTON (1931) demonstrated that lime sulphur gave sufficient control when applied within 30–72 hours after inoculation, while copper and elementary sulphur had only protective activity. In this early work, it was also observed that post-inoculation efficacy of lime sulphur was greater if spray droplets dried rapidly. In addition, it was also noted that treatments applied with lime sulphur remained protective after heavy rain, while elementary sulphur was ineffective after only a short period of rain (HAMILTON, 1931). In our experiments, lime sulphur applied alone tended to give lower scab incidences on leaves under heavy disease pressure compared to wettable sulphur applied alone (Table 4). However, leaf phytotoxicity was significantly higher compared to sulphur, especially in combination with mineral oil (Table 4). Therefore, a combination of sulphur and lime sulphur, seems to be a better approach, which provides the benefits of lime sulphur and reduces its phytotoxic effects. Our scab incidence data on sulphur plus lime sulphur treatments indicate that scab control with such a combination is similar to a combination of the wettable sulphur and copper sprays provided that they are applied before Mills infection periods occur. In addition, the use of wettable sulphur with copper or with lime sulphur resulted in similar leaf and fruit phytotoxicity. Hence, copper sprays in practical scab control might be replaced with sprays of wettable sulphur plus lime sulphur during the primary infection season.

At Randwijk, high inoculum pressure in combination with scab-conducive weather conditions caused severe scab epidemics later during the summer (Table 2). Under such conditions wettable sulphur had relatively poor efficacy during fruit swelling and ripening. This underlines the need for excellent scab control during the ascospore season. On the other hand, it also implies that elementary sulphur should be replaced with more effective products in rainy summers. ELLIS et al. (1994) claim that reduced rates of lime sulphur gave better scab control during summer than elementary sulphur applied alone and that results are comparable to conventional sprays under Ohio conditions. However, in their study phytotoxicity effects were not assessed. Our scab incidence results obtained from ascospore period onward indicate that lime sulphur in combination with a lower dosage of sulphur might be an alternative option during conidial infections.

The combination of high disease pressure and scab-conducive weather at Randwijk in 1998 and 1999 were ideal to differentiate treatment schedules. However, the recorded scab incidences are not representative for commercial orchards. Therefore, we conclude that lime sulphur in a combination with elementary sulphur might replace copper with respect to its efficacy against scab. It is a promising alternative option under low or moderate scab disease pressure. However, further investigations are needed to find treatment schedules of lime sulphur plus elementary sulphur with the lowest possible phytotoxicity. In addition, sanitation practices to reduce inoculum sources should be included as a management option to fulfill the requirements for season-long control of apple scab in organic apple growing.

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Literature

BIGGS, A. R. 1990: Apple scab. In: JONES, A. L. and H. S. ALDWINCKLE (Eds.): Compendium of apple and pear diseases. APS Press, St. Paul, Minnesota, 6–9.

BOSHUIZEN, A. J. and C. M. VERHEYDEN 1994: An agrometeorological network for warnings against scab in Belgium. Norwegian Journal of Agricultural Sciences, Supplement 17, 429–441.

COOLEY, D. R., J. W. GAMBLE, and M. MAZZOLA 1991: Effects of sulfur and copper fungicides on fruit finish, scab, and soil acidity. Fruit Notes 56, 1, 22–23.

CROXALL, H. E., D. C. GWYNNE, and J. E. E. JENKINGS 1952a: The rapid assessment of apple scab fungus on fruits. Plant Pathology 1, 89–92.

CROXALL, H. E., D. C. GWYNNE, and J. E. E. JENKINGS 1952b: The rapid assessment of apple scab fungus on leaves. Plant Pathology 2, 39–41.

ELLIS, M. A., L. V. MADDEN, and L. L. WILSON 1991: Evaluations of organic and conventional fungicide programs for control of apple scab, 1990. Fungicide and Nematicide Tests 46, 10.

ELLIS, M. A., L. V. MADDEN, L. L. WILSON, and D. C. FERREE 1994: Evaluations of organic and conventional fungicide programs for control of apple scab in Ohio. Ohio Agric. Res. Dev. Cent. Res. Cir. 298, 63–68.

ELLIS, M. A., D. C. FERREE, and L. V. MADDEN 1998: Effects of an apple scab-resistant cultivar on use patterns of inorganic and organic fungicides and economics of disease control. Plant Disease 82, 428–433.

EPPO/OEEP 1984: EPPO crop growth stage keys. European and Mediterranean Plant Protection organisation 142, 291–294.

EPPO/OEEP 1997: Guideline for the efficacy evaluation of plant products: Phytotoxicity assessment. European and Mediterranean Plant Protection organisation 135, 2, 31–36.

GENSTAT 5 COMMITTEE 1997: Genstat 5 Release 4.1 Reference Manual and Supplement. Clarendon Press, Oxford.

HAMILTON, J. M. 1931: Studies of fungicidal action of certain dust and sprays in the control of apple scab. Phytopathology 21, 445–523.

IFOAM 1989: Basic standards of organic agriculture. Tholey-Theley, BRD.

IFOAM 1998: Basic standards for organic production and processing. Tholey-Theley, BRD.

LEWIS, F. H. and K. D. HICKEY 1972: Fungicide usage on deciduous fruit trees. Annual Review of Phytopathology 10, 399–428.

MACHARDY, W. E. and M. J. JEGER 1982: Integrating control measures for the management of primary apple scab, *Venturia inaequalis* (Cke.) Wint. Protection Ecology 5, 103–125.

MACHARDY, W. E. and D. M. GADOURY 1989: A revision of Mills'criteria for predicting apple scab infection periods. Phytopathology 79, 304–310.

MACHARDY, W. E. 1996: Apple scab, biology, epidemiology and management. APS Press, St. Paul, Minnesota.

MILLS, W. D. and A. A. LA PLANTE 1951: Diseases and insects in the orchard. Cornell Ext. Bull. 711, 100.

PENROSE, L. J. 1989: A rational approach to apple scab control - the role of disease warning systems and curative spraying. Plant Protection Quarterly 4, 115–119.

SZKOLNIK, M. 1969: Maturation and discharge of ascospores of *Venturia inaequalis*. Plant Disease Reporter 53, 534–537.

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