A Low Input Strategy for Scab Control in Organic Apple Production

L. Jamar, B. Pahaut and M. Lateur
Centre wallon de Recherches agronomiques (CRA-W)
Département Sciences du vivant
rue de Liroux 4
B-5030 Gembloux
Belgium

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Abstract

The effectiveness of compounds such as sulphur, lime sulphur, copper and potassium bicarbonate for controlling primary scab was investigated in field experiments over two growing seasons in Belgium on high and medium scab-susceptible cultivars, 'Pinova' and 'Pirouette', respectively, and two *Vf* scab-resistant cultivars, 'Initial' and 'Topaz'. With the aim of reducing the amount of fungicide to be applied, two strategies were evaluated: (i) timing fungicide applications so that spraying occurred during the infection process, as determined by the RIMpro software warning system and (ii) using a tunnel sprayer machine for treatment applications.

In both years of the study, although there was high disease pressure, low rates of elemental sulphur (<40 kg ha^{-1} $year^{-1}$), combined with low rates of copper (<3 kg ha^{-1} $year^{-1}$) provided the best scab control and reduced scab severity on the fruit of 'Pinova' by ≥97% compared with a water control. Lime sulphur was more effective than wettable sulphur and appeared to be effective at temperatures below 10°C. Potassium bicarbonate significantly reduced apple scab and was, in some cases, as effective as wettable sulphur, using the same dosage. All treatments increased the yield of the scab-susceptible cultivars as well as that of the scab-resistant cultivars. Under these conditions, none of the treatments caused phytotoxicity, increased fruit russet, affected the summer density of the predatory mite, *Typhlodromus pyri* or resulted in undesirable residues on fruit at harvest.

INTRODUCTION

Under Belgian weather conditions, apple scab (*Venturia inaequalis* [Cooke] Winter) would cause fruit loss if no control measures were taken. Most of the commercial apple cultivars are susceptible to scab. The new commercially grown resistant cultivars are mainly the offspring of monogenic sources of scab resistance (*Malus floribunda* 821) that have proved to be susceptible to the epidemics of new virulent scab races 6 and 7 (Gessler et al., 2006).

There are only a few approved chemical compounds available for disease control following organic guidelines (EC, 2008). They are based primarily on sulphur and copper. A new EU Council Regulation (EC, 2009) allows only a reduced input of copper fungicides. In some European countries, the use of copper fungicides is not allowed. Sulphur compounds are often less effective than copper-based compounds, especially in cold weather (Holb et al., 2003). Most sulphur compounds have poor curative properties, the exception being lime sulphur, which might have curative properties against apple scab (Holb et al., 2003; Montag et al., 2005). Lime sulphur, is currently not allowed to be used in several European countries, although its use is permitted under EU regulations for organic production (EC, 2008). The repeated application of large amounts of sulphur compounds might have phytotoxic side-effects (Mills, 1947; Holb et al., 2003).

Several strategies have been proposed to reduce fungicide applications on apple (MacHardy, 1996). Various studies have shown that early warning systems based on disease forecasting models that give timely information on apple scab infection periods could limit the use of fungicides (MacHardy, 1996; Trapman and Polfliet, 1997; Rossi et

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al., 2007). An after-infection spray programme can significantly reduce fungicide applications for scab control (Holb et al., 2003). However, organic growers have not widely adopted this approach, probably because of the lack of (i) compounds with curative properties and (ii) an accurate local warning system. Therefore, the 'during-infection' spray strategy would be a promising scab control approach using compounds with poor curative properties and require fewer treatments than a preventive control strategy.

Another option for scab control may be to use natural substances as fungicides that have no known adverse affects on the environment and human health. Bicarbonates are one of several control options attracting attention (Schulze and Schönherr, 2003; Ilhan et al., 2006; Jamar et al., 2007). Growing scab-resistant cultivars would be another means of reducing fungicide use for scab control (MacHardy et al., 2001). In order to reduce the risks of crop loss from scab, a combination strategy of cultivar selection, fungicide selection and appropriate fungicide application timing could be used.

The objective of this study was to evaluate the effectiveness of the during-infection spray strategy using reduced amounts of inorganic fungicides such as sulphur, lime sulphur, copper and potassium bicarbonate for primary scab control. The effectiveness, phytotoxicity and effects on yield and fruit quality were studied on high, medium scab-susceptible cultivars and two *Vf* scab-resistant cultivars, in a modern apple orchard system.

MATERIALS AND METHODS

The study was conducted in 2005 and 2006 in two experimental apple orchards planted in 2002 at Gembloux, Belgium. The trees were grown according to organic production standards (EC, 2007; EC, 2008). The orchard soil was heavy loam and each year it received 1000 kg ha^{-1} of organic fertilizers (5% N) and 1000 kg ha^{-1} of hydrated lime for pH management. Orchard maintenance included a centrifugal training system (Simon et al., 2006). The trees reached an average height of 3 and 3.25 m in 2005 and 2006, respectively. For weed control under the tree rows, a cover-crop machine was successfully used four times a year. Grass alleys between the tree rows were kept short. Leaf analysis revealed calcium, boron, zinc and manganese deficiency, and therefore, eight correcting foliar treatments were applied during the growing season in both years.

The experiments were conducted following the EPPO-guidelines using high and medium scab-susceptible cultivars, 'Pinova' and 'Pirouette', respectively, in the first orchard and two *Vf* scab-resistant cultivars, 'Initial' and 'Topaz', in the second orchard. The trees were grafted on dwarfing rootstocks and planted in a single row system (3.5 x 1.5 m).

The experiment was conducted on 720 trees, involving five and four experimental spray programmes in both years in the first and second orchard, respectively. A split-plot design based on six randomized blocks with six replicates was used in each orchard. Each block comprised six rows (plots) of 24 dwarf trees. The plots consisted of 24 trees of four cultivars. The cultivars were randomized to subplots within the plots in 4 mono-cultivar groups of 6 trees. The treatments were randomised in plots within each of the 12 blocks. Each treatment combination was applied once in each block.

Treatments were applied with a 'Munckhof' tunnel sprayer (Munckhof, 5961 CV Horst, The Netherlands) to prevent spray drift and to reduce pesticide dispersal. In order to complete several treatments in a single run, the sprayer was fitted with six individual tanks. A recovery system that included a continuous recycling process in the tunnel sprayer led to an average of 30% of the applied spray mixtures being saved (Jamar et al., 2010a).

The six spray programmes in both years were as follows: (1) water control [UC]; (2) 1.6% potassium bicarbonate (0.8% during flowering) from Armicarb (Armicarb®100, Helena Chemical company, Collierville, TN, USA), [PB]; (3) 1.6% sulphur (0.8% during flowering) from wettable sulphur (Thiovit-jet, Syngenta Agro, Saint Cyr l'ecole Cedex, France) [WS]; (4) 1.6% sulphur (0.8% during flowering) from lime sulphur (Polisolfurio di Calcio, Polisenio, Lugo, Italy) [LS]; (5) 0.16% copper (0.05% from flowering till the end of May) from copper hydroxide (Kocide WG, Griffin Europe, Zaventem, Belgium) [CH]; and (6) 0.16% copper from copper hydroxide (Kocide WG) before flowering + 1.6% sulphur (0.8% during flowering) from wettable sulphur (Thiovit-jet) [WSCH]. All the treatments were applied at a low spray rate of 300 L ha^{-1}. In both 2005 and 2006, the treatments were applied in each primary infection period as determined by the RIMpro scab warning system, using the 'during-infection' spray strategy. This strategy consisted of spraying during the infection process. This meant spraying after ascospore inoculation and before hyphal penetration which occurs around 300 degree-hours (DH) of leaf wetness. Potential infection periods were recorded in the field using a METY computer-based weather recorder.

Eight and ten treatments for 'Pinova' and 'Pirouette' and six and eight treatments for 'Initial' and 'Topaz' were applied during the primary infection periods, from March to mid-June, in 2005 and 2006, respectively. One of them was applied during flowering in both years. Two additional treatments were applied during the summer.

For leaf severity assessments, a 1–9 scale was used, whereby: 1 = no scab lesions; 2 = ≤1% infected leaves with at least one lesion; 3 = ≤5% infected leaves with at least one lesion; 4 = 5–50% infected leaves with at least one lesion; 5 = ≥50% leaves with lesions with ≤5% leaf area spotted; 6 = 5–25% leaf area spotted; 7 = 25–50% leaf area spotted; 8 = 50–75% leaf area spotted; and 9 = maximum infection, leaves >90% black with scab (Lateur and Blazek, 2002).

Fruit scab incidence (FI) was calculated as the proportion of total harvested fruit with at least one scab lesion. Scab severity on fruit was assessed according to a scale of 1 to 6 whereby: 1 = no scab; 2 = 0–1%; 3 = 1–5%; 4 = 5–20%; 5 = 20–50%; and 6 = ≥50% fruit surface covered by scab. Fruit severity (FS) was defined as the mean proportion of the fruit surface covered by scab (Jamar et al., 2008).

No hand thinning was done during the growing season for any cultivars. Yield was assessed as the weight of all harvested fruit and classified into four size categories. Fruit russet was assessed according to EPPO standards. The first-class fruit was defined as fruit with a scab severity of <1%, russet <10% and size >60 mm, irrespective of all other parameters. Phytotoxicity was assessed on the whole leaf lamina following EPPO standards.

In 2006, on fruit of 'Pinova' and 'Topaz', fungicide residues were assessed on treated fruit (WSCH) in comparison with untreated control fruit (UC). Analyses were made using an overall fruit or peel mineral analysis at harvest and included 10-fruit sub-samples replicated six times for each treatment and cultivar.

Data were analysed using SAS software version 9.1 (SAS Institute, Cary, North Carolina, USA) and the Student-Newman-Keuls test was applied to determine whether the differences between treatments were significant.

RESULTS

Heavy disease pressure occurred during the primary infection seasons, as shown by the high scab infection rates recorded in untreated 'Pinova' plots (UC) in both years (Table 1). In both years, the combined copper and wettable sulphur treatments (WSCH) resulted in the best apple scab control on both leaves and fruit for all cultivars (Table 1). With this treatment, scab severity on fruit of the scab-susceptible cultivar 'Pinova' was reduced by 97 and 98% compared with the water control in 2005 and 2006, respectively. In 2005 and 2006, the lime sulphur treatments (LS) resulted in significantly lower scab damage on both leaves and fruit, compared with wettable sulphur treatments (WS), although the same amount of elemental sulphur was applied. Potassium bicarbonate (PB) significantly reduced apple scab and was, in some cases, as effective as wettable sulphur (WS), using the same amount of active ingredients for both treatments.

A moderate scab infection rate was observed on the untreated *Vf* scab-resistant cultivar 'Initial', but few scab infections were recorded on the untreated *Vf* scab-resistant cultivar 'Topaz', in 2005 and 2006 (Table 1). All the treatments significantly reduced the scab propagation on *Vf* cultivars. The combined sulphur and copper treatment (WSCH) prevented the scab propagation on 'Initial', with only eight and ten applications in 2005 and 2006, respectively. The amount of fungicides used in these experiments to control apple scab was not phytotoxic and did not increase fruit russet (data not shown).

In most cases, all treatments significantly increased overall yield per tree, reduced the proportion of fruit smaller than 60 mm and increased the amount of first-class fruit, compared with the untreated control (Table 1). For 'Pinova', the yield from plots treated with WSCH was 2.6 and 4.6 times greater than in the control plots in 2005 and 2006, respectively. In 2006, the fifth year, yield reached 40, 47, 58 and 59 ton ha^{-1} with the combination treatment of sulphur and copper (WSCH) for 'Pirouette', 'Pinova', 'Topaz' and 'Initial', respectively. For 'Initial', with a moderate scab rate, the sulphur-based treatments (WS, WSCH) also increased yield, compared with the non-sulphur-based treatments (UC, CH), largely as a result of the effects on fruit number per tree rather than on mean fruit weight. The lime sulphur treatment (LS) did not affect yields per ha, compared with wettable sulphur treatments (WS and WSCH) (Table 1).

Copper residues on fruit at harvest were very limited for 'Pinova' (Table 2). For 'Topaz', no significant difference of copper residues between the untreated control and WSCH treatments was registered. Standard and peel fruit analysis did not show any sulphur residue at harvest for either 'Pinova' or 'Topaz'. As in the leaf analysis, the fruit analysis also showed B, Zn and Mn deficiency in treated and untreated plots (Table 2).

DISCUSSION

'Pinova' was susceptible to scab, showing large scab lesions on leaves and fruit in untreated plots. The results of this study demonstrate that the during-infection spray strategy was effective in controlling apple scab in high scab-susceptible cultivars with a reduced amount of elemental sulphur ($\leq$40 kg ha^{-1} year^{-1}) and copper ($\leq$3 kg ha^{-1} year^{-1}). These amounts of fungicides were less than half of the amount usually used to control apple scab in organic production under humid climate conditions (Holb et al., 2003; Palmer et al., 2003).

With regard to *Vf* scab-resistant cultivars, few scab infections were recorded on untreated plots of 'Topaz', whereas significant scab damage was recorded on leaves and fruit from untreated plots of 'Initial', as a result of the presence of new scab races virulent to the *Vf* gene in the experimental orchard. The during-infection spray strategy using the combination of a low rate of sulphur and copper applied in the main primary infection periods was effective in preventing scab propagation on *Vf* scab-resistant cultivars. As reported in two long-term studies in Belgium, untreated plots of the *Vf* scab-resistant cultivar 'Topaz' were strongly scabbed, indicating that the *Vf* scab gene protection had been completely broken down by new virulent races (Jamar et al., 2009, 2010b).

Treatments were applied between 125 and 300 DH of leaf-wetness, after that ascospores had been discharged (according to the RIMpro simulation model). Susceptible tissues were present and the minimum temperature and leaf-wetness conditions for infection according to the revised Mills criteria were fulfilled. Less than 300 DH after rainfall, few ascopores reached the stage of penetration (Smereka et al., 1987; MacHardy, 1996). Sprays at less than 300 DH could be considered to have been applied during the infection process (before penetration) on germinating spores in which the primary stroma that allow the fungus to be protected by the plant cuticle had not yet formed.

The during-infection spray strategy has advantages over the preventive (before rainfall) spray strategy, including: (i) spray residues were less affected by washing; (ii) greater treatment effectiveness; and (iii) avoidance of unnecessary treatments. There are, however, potential problems. For example, the short spray-timing after the onset of the rain and spraying during an extended rainy period or during windy weather may be impractical or lead to poor control.

Lime sulphur was more effective than wettable sulphur alone, confirming the results of previous studies (Mills, 1947; Holb et al., 2003). Lime sulphur, which might have good curative properties (Holb et al., 2003; Montag et al., 2005), seems to have good staying attributes. As reported by Jamar (2007), lime sulphur applied on seedlings was less likely than wettable sulphur to be washed off the leaves by 24 mm of water under controlled conditions. Wettable sulphur would, therefore, require more frequent spray applications for primary scab control.

Applications of potassium bicarbonate alone during the growing season were not effective enough against scab using our strategy, suggesting that it needed to be supplemented (Jamar et al., 2007, 2008; Jamar and Lateur, 2007).

The scab damage was more severe in 2006 than in 2005, probably because (i) the weather conditions were more favourable to scab infection in 2006 and (ii) several untreated and poorly treated plots in 2005 led to high inoculum and heavier disease pressure during the 2006 primary infection season. In addition, the risk of early scab epidemics initiated by over-wintered conidia is high in organic orchards (Holb et al., 2005). All these facts could explain why some treatments were less effective in the 2006 primary scab season than in 2005, even though some sanitation practices, such as autumn leaf-shredding and early spring leaf-burying, were carried out between the two growing seasons, in order to limit the influence of the previous year (Holb, 2006).

Although some authors have reported apparent phytotoxicity or foliar damage with sulphur and copper treatments (Mills, 1947; Palmer et al., 2003; Holb et al., 2003), the amounts of active substances used in this study to control apple scab were not phytotoxic, and further, did not reduce yield. However, the use of copper was avoided during and after flowering, the treatment frequencies and fungicide doses were limited, particularly during flowering, and the treatments were applied at a low spray volume (300 L ha^{-1}).

The residual effects of treatments on *Typhlodromus pyri* densities were evaluated on each cultivar. Mite density assessments were made in May, June and July in both years. The amount of fungicides used in this experiment to control apple scab did not affect the summer density of the beneficial *T. pyri* (Jamar et al., 2008).

Copper residues on fruit at harvest from combined copper and sulphur treatments (WSCH) were low and below the maximal residue level (LMR) permitted in apple by EC regulations (5 and 50 mg kg^{-1} for copper and sulphur, respectively).

In conclusion, the present study has demonstrated the potential for controlling apple scab with reduced and non-damaging amounts of inorganic fungicides, using accurate timing of treatments and spray technology. Copper is still required for apple scab control in some organic apple production systems, particularly when lime sulphur is not allowed, as in Belgium. Currently, lime sulphur appears to be the sole remaining option for replacing copper when temperatures are below 10°C. Consequently, scab management in organic farming would be compromised if there were regulations restricting the use of copper in Belgium.

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Tables

Table 1. Effects of treatments on apple scab, yield and class 1 yield (C1) of 4- and 5-year-old trees in 2005 and 2006, respectively, in two organic apple orchards in Belgium.

Cultivar	Treat. code^{z}	2005					2006				
		LfS^{y} (1-9)	FI^{y} (%)	FS^{y} (%)	Yield^{x} (t ha^{-1})	C1^{w} (%)	LfS (1-9)	FI (%)	FS (%)	Yield (t ha^{-1})	C1 (%)
Pinova	UC	6.8a^{v}	85a	6.2a	8a	22a	7.0a	99a	18.7a	10a	1a
	PB	1.9b	55b	1.8b	15b	51b	4.9b	81b	7.7b	22b	25b
	WS	2.2b	45c	0.9bc	24c	59c	4.6c	83b	9.1b	24b	28b
	LS	1.8b	27d	0.4c	22c	78c	2.7d	45c	1.2c	44c	64c
	WSCH	1.1c	18d	0.2c	21bc	87c	2.7d	21e	0.4c	47c	75c
Pirouette	UC	3.1a	47a	1.2a	15a	60a	3.7a	39a	2.2a	26a	67a
	PB	1.4b	28b	0.4b	15a	76a	2.5b	21b	0.7b	31ab	83b
	WS	1.5b	24bc	0.3b	19a	79a	2.6b	21b	0.5b	34abc	84b
	LS	1.2b	15bc	0.2b	18a	89a	2.0c	4d	0.0c	37bc	95c
	WSCH	1.1b	11c	0.1b	18a	93a	1.9c	2c	0.0c	40c	96c
Initial	UC	2.3a	22a	1.1a	29a	92a	2.6a	13a	0.8a	45a	88a
	CH	1.0b	6b	0.2b	30a	94a	1.1b	2b	0.1b	49a	93b
	WS	1.1b	10b	0.3b	38a	96a	1.1b	9ab	0.5ab	55a	94b
	WSCH	1.0b	0b	0.0b	39a	96a	1.0b	0b	0.0b	59a	96b
Topaz	UC	1.0a	0a	0.0a	32a	94a	1.1a	0a	0.0a	49a	92a
	CH	1.0a	0a	0.0a	27a	95a	1.0a	0a	0.0a	62a	87a
	WS	1.0a	0a	0.0a	30a	94a	1.0a	0a	0.0a	61a	90a
	WSCH	1.0a	0a	0.0a	26a	96a	1.0a	0a	0.0a	58a	88a

[z] Treatment code: UC = untreated control, PB = potassium bicarbonate, WS = wettable sulphur, LS = lime sulphur, WSCH = wettable sulphur + copper hydroxide, CH = copper hydroxide.

[y] LfS = leaf severity. FI = fruit incidence. FS = fruit severity: mean scabbed area.

[x] The calculation base for yield (ton ha^{-1}) was 1900 trees per ha.

[w] Class 1 includes fruit with scab severity <1%, size >60 mm and russet <10%.

[v] Values within columns and cultivars followed by different letters are significantly different ($P \leq 0.05$) according to the Student-Newman-Keuls multiple range tests.

Table 2. Effects of applied treatments on concentration of mineral elements in fruit tissues (mg 100 g^{-1} fresh tissue) at harvest in 2006.

Analysis[z]	Cultivar	Treatment	% DW[y]	Cu	Zn	B	S
Standard	Pinova	WSCH	14.48[x]	0.044[w]	0.027	0.168	4.59
	Pinova	Control	15.69	0.036	0.019	0.194	4.69
		F-test[v]	*	*	ns	ns	ns
	Topaz	WSCH	13.73	0.038	0.025	0.155	3.94
	Topaz	Control	13.70	0.032	0.019	0.150	3.93
		F-test	ns	ns	ns	ns	ns
Peel	Pinova	WSCH	21.10	0.081	0.086	0.301	8.34
	Pinova	Control	22.95	0.067	0.057	0.376	8.95
		F-test	*	*	*	*	ns
	Topaz	WSCH	19.30	0.061	0.066	0.252	8.18
	Topaz	Control	19.82	0.059	0.051	0.235	8.51
		F-test	ns	ns	ns	ns	ns

[z] Standard: whole fruit analysed using standard methods; Peel: only the peels were analysed.

[y] DW = dry weight. All other nutrients (N, P, K, Ca, Mg, Mn, Fe, K/Ca) were within the adequate range and there were no treatment differences.

[x] Values represent the means of six replicates ($n = 6$) of 10 fruit each.

[w] Normal ranges for apple (standard fruit quality) are Cu: 0.02–0.05, Zn: 0.03–0.05, B: 0.2–0.4 and S: 3–5 mg 100 g^{-1} fresh tissue.

[v] F-test = * significant at $P \leq 0.05$, ns (non significant) at $P > 0.05$.