Strategies to reduce copper use in organic apple production

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2 authors:

L. Jamar
Walloon Agricultural Research Centre CRA-W

M. Lateur
Walloon Agricultural Research Centre CRA-W

Strategies to Reduce Copper Use in Organic Apple Production

L. Jamar and M. Lateur
Centre wallon de Recherches Agronomiques
Department of Biological Control & Plant Genetic Resources
Rue de Liroux 4, B-5030 Gembloux
Belgium

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Abstract

Various strategies for controlling apple scab (*Venturia inaequalis*) were studied under field conditions over two growing seasons. An experimental organic orchard, designed especially for this trial, was planted with four partially scab-resistant cultivars ('Rubinstep-Pirouette', 'Reinette des Capucins', 'Reinette de Waleffe' and 'Pinova', which was used as the control) and four *Vf* scab-resistant cultivars (Topaz, Zvatava, Initial and JN 20/33/58). As the virulent scab race 7 is present in Belgium, one of the objectives was to test strategies to prevent *Vf* resistance breakdown. In order to drastically limit copper use, seven spray treatments were tested, including: 1. wettable sulphur (WS), 2. copper and wettable sulphur combined (CS), 3. wettable sulphur and lime sulphur combined (WSLS), 4. potassium bicarbonate (PB), 5. silicon (Si), 6. untreated control (Control) and 7. conventional fungicide control (IFP). The timing of fungicide applications was determined by the RIMPRO software warning system on the presence of airborne scab ascospores in orchards, taking into account forecasted weather conditions. A prototype of the 'tunnel sprayer' machine was used to apply fungicides. Compared with the control, fruit scab severity on cv. Pinova was significantly reduced by 99, 99, 91 and 68% in 2003 and by 100, 100, 92 and 52% in 2004 on trees sprayed with IFP, CS, WSLS and PB, respectively. These results were obtained with only 10 spray applications at lower fungicide rates despite the higher scab infection pressure in 2004. Good timing seems to be the most important factor in a spray treatment. Most of the treatments (IFP, CS, WSLS, WS and PB) also significantly reduced powdery mildew (*Podosphaera leucotricha*) infections. In both years, treatments with sulphur, copper and lime sulphur did not cause any phytotoxicity on leaves and fruits. A quantitative provisional apple scab control programme using copper and wettable sulphur was set up, including all potential climatic situations and degrees of infection risk in Belgium. The potential use and limits of potassium bicarbonate as an active substance for controlling apple scab and powdery mildew are discussed.

INTRODUCTION

Consumer demand for certified organic apples has increased throughout Europe, but production is constrained by disease control difficulties. Apple scab, caused by *Venturia inaequalis* (Cooke) G. Wint., is a major disease of apple trees. It results in important economic losses, especially in humid agricultural areas, where control is necessary for commercial apple production. Crop losses in Belgium caused by apple scab would be about 70% if no control measures were taken; an average of 15–25 conventional spray applications per season are used to prevent apple yield loss under Belgium's weather conditions. In the organic production system (OPS), the use of synthetic fungicides is not permitted and scab is controlled using mainly copper and sulphur fungicides. Copper has a poor ecotoxicological profile and there are new European Union (EU) restrictions on copper use. Therefore, alternatives to copper fungicides need to be investigated. Very few fungicides are available in the OPS and apple scab control is difficult under normal situations. With the use of commercial apple cultivars that are very susceptible to diseases, apple scab control is becoming even more difficult.

Other options for controlling apple scab are elemental sulphur and lime sulphur products. Elemental sulphur is a contact fungicide with a weak protective activity. Lime sulphur is effective against apple scab and might have good curative qualities but, although its use is permitted under EU regulations for organic production (Regl. CEE N.2092/91), it is not allowed to be used in Belgium or France. The drawback of using curative treatments based on lime sulphur sprays is that its effectiveness against apple scab is often combined with severe phytotoxicity and reduced yield quality (Mills, 1947; Palmer et al., 2003; Holb et al., 2003). Further control options that have recently received attention include bicarbonates and silicates. These 'biocompatible' chemicals are particularly interesting because they have fungicidal properties combined with very low mammalian and environmental toxicities (Horst et al., 1992; Menzies et al., 1992).

The aim of this study was to develop a successful strategy for the control of apple scab using environmentally friendly substances which are compatible with OPS. Growers need greater scientific knowledge on profitable and good-quality organic fruit production in Belgium. It is important to develop new strategies for the management of organic orchards that take into account a maximum of parameters playing a key role inside this specific agro-ecosystem. Commercial growers still need to use chemical products, but we have to improve the effectiveness of these products and choose the optimal combinations of factors and techniques in order to reduce input rates. These factors include: Choice of adapted varieties with low susceptibility to the major diseases and with good commercial potential, use of warning systems using accurate software to identify infection risk periods, maintenance of a low infection potential, use of accurate mechanical methods for spraying and weed control, use of organic manures and good soil management to improve biological activity, balanced management of the trees and fruit production based on the SOLAXE concept developed by the MAFCOT group (Lespinasse and Delort, 1993) and creation of an ecological environment favorable to useful fauna.

MATERIALS AND METHODS

Orchard and Equipment

The experiment was conducted in 2003 and 2004 in a well-maintained experimental apple orchard planted in 2002 at Gembloux, Belgium. A split-plots design was adopted based on two randomized blocks. Each block was composed of six rows (plots) of 24 dwarf trees grafted onto M9 rootstocks. In one part of the orchard, the blocks contained four partially scab-resistant cultivars ('Rubinstep-Pirouette', 'Reinette des Capucins', 'Reinette de Waleffe' and 'Pinova'). In the other part, the blocks contained four *Vf* scab-resistant cultivars ('Topaz', 'Zvatava', 'Initial' and 'JN 20/33/58'). Each of the 10 experimental spray treatments was applied to a minimum of 144 trees. The treatments were applied with an experimental prototype of a tunnel sprayer (Munckhof, 5961 CV Horst, The Netherlands) in order to prevent spray drift and to save on pesticides. Potential infection periods, based on the criteria described by Mills (1947), were recorded in the field with a METY computer-based weather recorder connected to a RIMpro scab warning system (Bodata Co. Ltd, Dortrecht, The Netherlands) (Boshuizen and Verheyden, 1994) from 15 March to 31 July in both 2003 and 2004. This apple scab forecasting system is based on the relationships between temperature, amount and duration of rainfall, duration of leaf wetness and scab incidence or severity.

Treatments

Various spray treatments based on reduced copper were applied to polygenic resistance cultivars. The treatments in both years were: 1. untreated control (Control); 2. conventional, based on integrated fruit production guidelines (IFP); 3. copper and wettable sulphur, based on organic guidelines on low copper and low sulphur rates (CS); 4. a compensation treatment of wettable sulphur and lime sulphur based on higher sulphur rates (WSLS); 5. potassium bicarbonate (PB); and 6. wettable sulphur, based on low sulphur rates in 2003 (WS) and silicon in 2004 (Si). In 2003, PB was associated with four treatments of Myco-Sin. The treatments are shown in Table 1. The applied products included: Thiovit jet (wettable sulphur, 80%, Syngenta Crop Production, The Netherlands), Kocide WG (copper hydroxide, 40%, Griffin Europe N.V), Polisolfurio di Calcio (lime sulphur, 27%, Polisenio, Italy), potassium bicarbonate (99.5% $KHCO_3$ Sigma-Aldrich sa, Belgium), Myco-Sin (from Andermatt Biocontrol AG, Switzerland), Siliforce (silicon, 0.7%, agro-Solutions BV, The Netherlands), Candit (kresoxim-methyl, 50%, BASF, Belgium), Merpan 80 WG (captan, 80%, Makhteshim-agan Holland BV, The Netherlands), Scala (pyriméthanil, 37%, Aventis CropScience Benelux SA/NV), Hermoo Dodine SC (dodine, 40.4%, Hermoo Belgium NV), Delan 70 WG (dithianon, 70%, BASF Belgium) and Geyser (difenoconazole, 25%, Syngenta Crop Protection NV). All the treatments were applied at low spray rates (300 l/ha) and dosages in order to reduce the phytotoxic effect of the copper and lime sulphur. No fungicides other than the indicated treatments were used during the season, except in autumn when two post-harvest copper treatments (0.6 kg/ha) were applied to reduce canker development. In 2003, the strategy was to use preventive spray treatments based on tree growth and weather forecasts, whereas in 2004 a 'stop-spray' strategy was adopted and products were applied during or just after each infection period. With the *Vf* scab-resistant cultivars, the aim was to test treatments that would enhance the durability of the *Vf* scab gene protection in order to prevent its breakdown by virulent races. The treatment consisted of applying protective or 'stop-spray' substances when high primary infection risks were forecast. The applied treatments were: 1. Control; 2. IFP; 3. CS; and 4. WS. In order to study the environmental impact of the various spray treatments, we followed the presence of several beneficial organisms such as *Typhlodromus pyri* which are used as agro-environmental indicators.

Disease Assessment

Disease assessments were made on leaves and fruits in both years. In order to assess apple scab intensity on the trees, a model based on a 1–9 scale was used whereby 1 = no scab lesions and 9 = 100% of the leaf area on each plant covered by lesions (Lateur and Populer, 1996; Lateur and Blazek, 2002). Yield was based on the weight of harvested fruits. Fruits from the whole harvest were classified according to their symptoms in October. In order to assess scab incidence and severity, all the harvested fruits were assessed according to a scale of 1–9, whereby 1 = no scab and 9 = > 75% of the fruit covered by scab. Severity was defined as the mean proportion of the fruit surface covered by scab.

Data Analysis

The percentage data were transformed into arcsine angles before performing an analysis of variance. The data were analysed using statistical SAS software, and the Student-Newman-Keuls test was applied to determine whether the differences between treatments were significant. All the statistical evaluations were conducted at a significance level of $P<0.05$.

RESULTS

In 2003 and 2004 there were 9 and 11 infection periods, respectively, recorded from the end of March to the beginning of June (Table 1). At the study site and throughout Belgium, the primary ascospore infection was higher in 2004 than in 2003. The Mills (1947) infection periods were severe in 5 instances in 2003 and 8 in 2004, moderate in 2 instances in both years, and low in 2 instances in 2003 and 1 in 2004. The strongest impact of the disease was therefore observed in the water control spray programme in 2004.

No scab infection was recorded on untreated *Vf* scab-resistant cultivars in either 2003 or 2004, except for the cultivar 'Initial'. All the treatments prevented the propagation of this new virulent scab race, with only eight applications in each year.

Among the four polygenic resistant cultivars, 'Pinova' and 'Rubinstep' showed significant apple scab symptoms on their leaves and fruits. There was heavy disease pressure during the primary infection seasons, as revealed by the high scab infection rates recorded in untreated 'Pinova' plots in both 2003 and 2004. In both years, total effectiveness was recorded with the IFP and CS treatments (Table 2). For the susceptible 'Pinova', disease incidence on fruits was significantly reduced by 100, 98, 89 and 52% in 2003 and 99, 99, 86 and 35% in 2004, on trees sprayed with IFP, CS, WSLS and PB, respectively. Disease severity on 'Pinova' fruits was significantly reduced by 99, 99, 91 and 68% in 2003 and 100, 100, 92 and 52% in 2004, on trees sprayed with IFP, CS, WSLS and PB, respectively. In the CS treatment, the total amount of copper (a.i.) and sulphur (a.i.) used during the spring was 1.8 and 45.5 kg/ha in 2003 and 1.2 and 31.5 kg/ha in 2004, respectively. Disease control in 2004 was as effective as it had been in 2003, although there was higher infection pressure and smaller quantities of copper and sulphur were used. The good scab control was probably due to appropriate timing of the treatments. For 'Pinova' in 2004, the CS treatments resulted in significantly lower scab damage on the leaves compared with the WSLS treatments, but did not result in significantly lower scab damage on fruits. The Si treatments significantly reduced scab damage on both the leaves and fruits of 'Pinova' in 2004.

With regard to the PB treatments, 13.5 and 12 kg/ha of potassium bicarbonate and Myco-Sin, respectively, were used in 2003 and 18 kg/ha of potassium bicarbonate in 2004. In 2003, PB did not significantly reduce apple scab intensity on leaves but it did significantly reduce apple scab incidence and severity on the harvested fruits of 'Pinova' and 'Rubinstep' compared with water control treatments. In 2004, PB significantly reduced apple scab intensity on the leaves of 'Pinova', a scab-susceptible cultivar, and 'Rubinstep', a moderately resistant cultivar, and it significantly reduced apple scab incidence and severity on fruits compared with the water control treatment for 'Pinova'.

All the treatments increased mean harvested fruit weight per tree for 'Pinova' but not for 'Rubinstep' or 'R. Capucins' in 2004, but PB did not enhance the mean harvested fruit weight in 2003 (Table 2). The effects of apple scab spray treatments on powdery mildew (*Podosphaera leucotricha*) were assessed in July 2003 and 2004. All of them significantly reduced powdery mildew occurrence, but the infection pressure was low in both seasons (data not shown). With regard to phytotoxicity, treatments with sulphur, copper and lime sulphur did not have an adverse effect in either year. The WSLS and CS treatments did not reduce fruit yield compared with the IFP treatment.

DISCUSSION

This study demonstrated total apple scab control using IFP and CS treatments involving few sprays in both 2003 and 2004. It shows that the treatment timings were correct in relation to recorded infection periods, especially in 2004 when a 'stop-spray' strategy was used. In 2004, the fungicides were applied shortly after rainfall, sometimes on drying leaves, during infection periods. Very small annual amounts of copper and sulphur were used with CS treatments. The effectiveness of the CS treatments might also be attributed to the use of a high-performance tunnel sprayer and the presence of young fruit trees. On leaves and fruits, the CS treatments tended to provide better scab control than WSLS.

Although some authors have reported poorer leaf appearance under organic management (Palmer et al., 2003; Holb et al., 2003), our study showed no significant effects of fungicide treatments compatible with the OPS on leaf phytotoxicity, fruit damage and yield. There are three possible reasons for this: 1. the use of lime sulphur and copper were avoided during flowering and copper was not used after flowering in 2003 or 2004; 2. applications were made using a tunnel sprayer at a low rate of about 300 l/ ha; and 3. treatment frequencies and product doses were limited.

Studies on the non-target effects of fungicide sprays have shown that lime sulphur is toxic to plant organs (Vyas, 1988). Further investigations are needed to demonstrate how to control scab with 'stop-spray' wettable sulphur or curative lime sulphur treatments without the use of copper and without high phytotoxic doses of lime sulphur. As recently revealed, curative treatments using lime sulphur, applied 20–30 h (Trapman, 2001) or 35–45 h (Holb, 2003) after predicted infection periods, provide effective primary apple scab control under organic growing conditions in The Netherlands, but damaging effects on yield were also recorded.

Earlier greenhouse experiments have shown that potassium bicarbonate is also effective against apple scab (Jamar and Lateur, 2006). The initial strategy for the PB treatments in 2003 was to alternate Myco-Sin with potassium bicarbonate in order to initiate the prophylactic stimulation of induced resistance with Myco-Sin and the short-term stopping effects of bicarbonates. But this strategy did not provide satisfactory results and therefore bicarbonates were used alone in 2004. Since a proportion of the Myco-Sin spraying mixture is acid, while bicarbonates need to act under alkaline conditions, these products cannot be used together and seem to be incompatible in an intense spray programme. Myco-Sin has been reported to promote disease resistance on crops (Tamm et al., 2004). As recommended, it has to be applied in a preventative way at a high water rate and has to be absorbed into the plant tissue before rain. The hardening of the cuticle, together with the acidic pH of 3.5–3.8 of the spray solution, should create an environment that does not favour spore germination. The additional yeast cell and equisetum extracts should enhance this process, acting as sticking and spreading agents that support the development of microbial antagonists. The sulphuric acidic clay minerals release aluminium ions and silicon that should cause the prophylactic effect. The results presented here, for one growing season (2004), show that silicon contributes to apple scab control. It has been reported to induce resistance in plants (Menzies et al., 1992; Bowen et al., 1992; Reynolds et al., 1996).

The efficiency of bicarbonate salts in controlling apple scab, as reported here, together with the improvement of disease control treatments using bicarbonates (Horst et al., 1992; Ziv and Zitter, 1992; McGovern, 2003; Schulze and Schönherr, 2003), suggest that this simple compound is a good 'biocompatible' fungicide. The compounds are ubiquitous in nature, naturally present in human food, available to the general public for non-pesticide uses, and required for normal functions in human, animal, plant and environmental systems.

Some issues, however, need further examination before the technology can be recommended for commercial adoption against apple scab. Potassium bicarbonate acts as a contact fungicide and is not likely to be systemic or curative; therefore, the better the coverage, the greater the effectiveness. In contrast, after germination, apple scab caused deep-seated fungal infections with powdery mildew. The timing of applications is therefore crucial. A long-lasting effect cannot be expected. Bicarbonates are quickly converted to ineffective compounds and are highly water-soluble, and they will be washed off the leaves by a small amount of precipitation. They therefore require frequent spray applications determined by the presence of ascospores in the orchards and the infection risk periods forecast by modern local warning systems. In order to enhance the stability of bicarbonates on leaves and therefore scab control effectiveness, additional research is needed to determine the optimal formulation of this compound, such as the appropriate mixture with mineral oils and with surfactant supplies in well-buffered alkaline solutions.

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Literature Cited

Bowen, P., Mensies, J., Ehret, D., Samuels, L. and Glass, A.D.M. 1992. Soluble silicon sprays inhibit powdery mildew development on grape leaves. J. Am. Soc. Hort. Sci. 117: 906-912.

Boshuizen, A.J. and Verheyden, C.M. 1994. An agrometeorological network for warnings against scab in Belgium. Norw. J. Agric. Sci. 17 (Suppl.): 429-441.

Holb, I.J., De Jong, P.F. and Heijne, B. 2003. Efficacy and phytotoxicity of lime sulphur in organic apple production. Ann. Appl. Biol. 142: 225-233.

Horst, R.K., Kawamoto, S.O. and Porter, L.L. 1992. Effect of sodium bicarbonate and oils on the control of powdery mildew and black spot of roses. Plant Dis. 76: 247-251.

Jamar, L. and Lateur, M. 2005. Recherche de méthodes alternatives de lutte contre la tavelure du pommier dans le cadre de la production biologique : trois années d'expérimentation au CRA-W. Le Fruit Belge 515: 70-76.

Jamar, L. and Lateur, M. 2006. Control of apple scab with bicarbonates salts. (in press)

Lateur, M. and Populer, C. 1996. Evaluation and identification methods used for apple genetic resources at the State Plant pathology Station in Gembloux, Belgium. In: European Malus Germplasm. Case, H.J. (ed.). ECP/GR and IPGRI, Rome. p. 78-87.

Lateur, M. and Blazek, J. 2002. Evaluation descriptors for Malus. In: Report of a Working Group on Malus/Pyrus. ECP/GR and IPGRI, Rome. p.76-82.

Lespinasse, J.M., Delort, F. 1993. Regulation of fruiting in apple. Role of the bourse and crowned brindles. Acta Horticulturae. 349: 229-246.

McGovern, R.J., Winston, A.E., Rouse, R.E. and Welch, A.W. 2003. Reduction of defoliation in citrus caused by Mycosphaerella citri with a novel biocompatible fungicide. Plant Dis. 87 (2): 134-138.

Menzies, J., Bowen, P., Ehret, D. and Glass, A.D.M. 1992. Foliar application of potassium silicate reduce severity of powdery mildew on cucumber, muskmelon and zucchini squash. J. Am. Soc. Hort. Sci. 117: 902-905.

Mills, W.D. 1947. Effects of sprays of lime sulphur and of elemental sulphur on apple in relation to yield. Cornell Experiment Station Memoir. 273: p. 38.

Palmer, J.W., Davies, S.B., Shaw, P.W. and Wünsche J.N. 2003. Growth and fruit quality of 'Braeburn' apple (Malus domestica) trees as influenced by fungicide programmes suitable for organic production. New Zealand J. of crop and Hort. Science. 31: 169-177.

Reynolds, A.G., Veto, L.J., Sholberg, P.L., Wardle, D.A. and Haag, P. 1996. Use of potassium silicate for the control of powdery mildew (Uncinula necator 'Schwein' Burrill) in Vitis vinifera L. cultivar bacchus. Am. J. Enol. Vitic. 47: 421-428.

Tamm, L., Amsler, T., Böger, N. and Fuchs, J.G. 2004. Die Wirkung von Myco-Sin gegen den Apfelschorf in Abhängigkeit der Schwefelformulierung [Effects of Myco-Sin against apple scab]. In Häseli, A., (ed.). Tagungsband zur FiBL Bioobstbautagung 28.01.2004 in Frick. Forschungsinstitut für biologischen Landbau, Frick. p. 31-34.

Trapman, M. 2001. Schurft curatief weren met kalkzwavel. Fruittelt. 91: 10-11.

Schulze, K. and Schönherr, J. 2003. Calcium hydroxide, potassium carbonate and alkyl polyglycosides prevent spore germination and kill germ tubes of apple scab (Venturia inaequalis). Journal of Plant Disease and Protection. 110 (1): 36-45.

Vyas, S.C. 1988. Nontarget effects of agricultural fungicides. London, UK. CRC Press. p. 443.

Ziv, O. and Zitter, T.A. 1992. Effects of bicarbonates and film-forming polymers on cucurbit foliar diseases. Plant Dis. 76: 513-517.

Tables

Table 1. Apple scab spray treatments in 2003 and 2004.

Year	Spray date	Ph. Stge.[c]	Rain[d] (mm)	Spray programmes[eg]									
				IFP		CS		WSLS		WS (2003) Si (2004)		PB	
				a.i.[f]	kg ha^{-1}	a.i.	kg ha^{-1}	a.i.	kg ha^{-1}	a.i.	kg ha^{-1}	a.i.	kg ha^{-1}
2003[a]	29/3	D	0.4	DO	1.5	C+WS	0.3+3	WS	4	WS	3	PB	1.5
	1/4	D	22.4	CA	1.2	C	0,3	WS	4	WS	1	MY	3
	20/4	E2	32.2	CA	1.2	C+WS	0.3+5	WS	6	WS	4	PB	1.5
	25/4	F1	33.6	DI	0.5	C+WS	0.3+5	LS	4	WS	5	MY	3
	29/4	F1	52	DI	0.52	C+WS	0.3+5	WS	5	WS	5		1.5
	5/5	F2	62.6	DI	0.52	C+WS	0.3+5	WS	5	WS	5	PB	1.5
	8/5	F2	74	CA	1.2	C+WS	0.3+4	WS	4	WS	3	PB	1.5
	11/5	H	76	DF	0.01	S	3	WS	3	WS	3	MY	3
	16/5	I	100	-	-	S	3	WS	3	-	-	PB	1.5
	21/5	J	133	KR	0.1	S	4	LS	3.5	WS	3	PB	1.5
	1/6	J	157	KR	0.1	S	2.5	WS	2.5	WS	2.5	MY	3
	3/6	J	168	-	-	S	3	WS	3	-	-	-	-
	6/6	J	186	-	-	S	3	WS	3	WS	2.5	PB	1.5
	12/6	J	186	KR	0.1	S	3	LS	3.5	-	-	PB	1.5
2004[b]	21/3	D	4.4	DO	0.6	C	0.3	LS	4	Si	0.2	PB	3
	05/4	D	10.1	DO	0.6	C+WS	0.3 4	LS	4	Si	0.2	PB	3
	20/4	E2	43.3	PY	0.3	C+WS	0.3+4	LS	5	Si	0.2	PB	3
	30/4	F1	52.5	Py+Ca	0.3+1.2	C+WS	0.3+5	WS	4	Si	0.2	PB	3
	06/5	F1	56.9	DI	0.52	WS	2	WS	4	Si	0.2	PB	3
	21/5	F2	91.5	KR	0.1	WS	3.5	LS	3	Si	0.2	PB	3
	31/5	F2	97.1	KR	0.1	WS	5	LS	3	Si	0.2	PB	3
	10/6	I	129.9	KR	0.1	WS	4	LS	3	Si	0.2	PB	3
	29/6	J	143.3	KR	0.1	WS	5	LS	3	Si	0.2	PB	3
	22/7	J	216.7	WS	5	WS	5	WS	5	WS+Si	5+0.2	WS	5

[a] Primary infection dates according to RIMpro (Mills criteria) during spring 2003 were: 29/03 = B; 03/04 = B; 21/04 = B; 26/04 = H; 28/04 = B; 01/05 = B; 02/05 = B; 06/05 = M; 09/05 = B; 18/05 = L; 19/05 = H; 21/05 = H; 24/05 = H; 02/06 = H; 05/06 = B; 08/06 B; 10/06 = M; 15/06 = L where B: beginning infection; L: low infection; M: moderate infection; H: high infection.

[b] Primary infection dates according to RIMpro (Mills criteria) during spring 2004 were: 20/03 = L; 03/04 = B; 06/04 = H; 22/04 = M; 30/04 = H; 04/05 = H; 08/05 = M; 21/05 = B; 30/05 = H; 02/06 = H; 04/06 = H; 10/06 = H; 15/06 = B; 18/06 = H; 27/06 = B; where B: beginning infection; L: low infection; M: moderate infection; H: high infection.

[c] Phenological stage for cv. Pinova according to J. Fleckinger

[d] Additional rain calculated since 15 March in 2003 and 2004

[e] Control spray programme is not shown because only water was used.

[f] Active ingredient

[g] IFP = integrated fruit production, DO = Dodine, CA = captane, KR = Kresoxym méthyl, DI = Dithianon, PY = Pyriméthanil, DF = Difénoconazole, WS = wettable sulphur, LS = lime sulphur, C = copper hydroxide, MY = Myco-Sin, PB = potassium bicarbonate, Si = Siliforce.

Table 2. Effects of treatments on apple scab and yield for cv. Pinova , cv. Pirouette and cv. R. Capucins in 2003 and 2004.

cv. [u]	Treatment [v]	2003					2004				
		Apple scab			Yield		Apple scab			Yield	Fruit
		Int. [w]	Inc. [x] % [c]	Sev. [y] %	(kg per tree) [z]	Fruit weight (g)	Int.	Inc. %	Sev. %	(kg per tree)	weight (g)
Pin	IFP	1.1 a	0.1 a	0.0 a	4.1 a	156 b	1.0 a	0.4 a	0.0 a	9.7 ab	158 ab
Pin	CS	1.9 a	0.7 a	0.0 a	3.8 a	173 a	1.0 a	0.8 a	0.2 a	11.6 a	171 a
Pin	WSLS	2.2 a	4.7 a	0.2 a	4.0 a	173 a	1.6 b	8.7 a	0.9 a	12.9 a	162 ab
Pin	WS_{2003} Si_{2004}	2.7 a	8.3 a	0.3 a	4.6 a	168 a	3.4 c	33.8 b	5.4 a	9.2 ab	150 b
Pin	PB	3.7 b	20.1 b	0.7 a	3.0 b	154 b	3.9 c	40.5 b	6.1 a	7.5 ab	145 b
Pin	Control	4.3 b	41.6 c	2.2 b	3.0 b	149 b	5.1 d	61.9 c	11.9 b	5.3 b	146 b
Rub	IFP	1.1 a	0.0 a	0.0 a	1.1 a	180 a	1.0 a	0.0 a	0.0 a	5.6 a	177 a
Rub	CS	1.2 a	0.0 a	0.0 a	0.5 a	192 a	1.0 a	0,8 a	0.0 a	4.5 a	185 a
Rub	WSLS	1.3 a	0.0 a	0.0 a	0.7 a	161 a	1.3 b	2.5 a	0.1 a	4.6 a	186 a
Rub	WS_{2003} Si_{2004}	1.5 a	0.6 a	0.0 a	1.2 a	182 a	2.0 c	25.5 b	1.0 b	4.7 a	183 a
Rub	PB	2.1 b	4.3 b	0.1 a	0.9 a	167 a	1.8 c	22.0 b	0.9 ab	5.3 a	195 a
Rub	Control	2.4 b	14.9 c	0.7 b	1.1 a	193 a	2.8 d	29.9 b	1.2 b	4.0 a	187 a
Cap	IFP	1.0 a	0.0 a	0.0 a	0.8 a	151 a	1.0 a	0.0 a	0.0 a	5.9 ab	201 a
Cap	CS	1.0 a	0.0 a	0.0 a	0.9 a	164 a	1.0 a	0.0 a	0.0 a	5.0 ab	181 ab
Cap	WSLS	1.0 a	0.0 a	0.0 a	1.3 a	159 a	1.0 a	0.0 a	0.0 a	6.2 a	187 ab
Cap	LS_{2003} Si_{2004}	1.0 a	0.0 a	0.0 a	1.4 a	145 a	1.0 a	0.0 a	0.0 a	5.2 ab	174 b
Cap	PB	1.0 a	0.0 a	0.0 a	1.3 a	147 a	1.0 a	0.0 a	0.0 a	4.3 ab	182 ab
Cap	Control	1.0 a	0.0 a	0.0 a	0.6 a	129 b	1.0 a	0.0 a	0.0 a	3.7 b	189 ab

[U] Pin = cv. Pinova, Rub = cv. Rubinstep-Pirouette, Cap = cv. Reinette des Capucins
[V] IFP = integrated fruit production (synthetic fungicides), CS = copper and sulphur, PB = potassium bicarbonate, WS = wettable sulphur, Si = silicon (Siliforce formulation) , LS = liquid lime sulphur, Control = untreated plots. In 2003, PB was combined with Myco-Sin, see Table 1.
[W] Intensity (Int.) = Global assessment scale for scab infection on leaves using a 1–9 scale; June assessment shown here.
[X] Incidence (Inc.) = Proportion of total harvested fruits with at least one spot.
[Y] Severity (Sev.) = Mean scabbed area or mean proportion of fruit surface covered by scab.
[Z] Mean harvested fruit weight per tree and average fruit weight.
Data within the same column and the same cultivar followed by the same letter are not significantly different (P = 0.05) according to the Student-Neuwman-Keuls multiple range tests. Number of assessed trees by treatment x cultivar is 36.