Preventative and curative applications of carbonates against apple scab (*Venturia inaequalis*) in organic apple orchards

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Abstract

In the EC, for a long time, only copper- and sulphur-based products were allowed to control a variety of diseases on different crops. However, it is well-known that these products also have negative side effects on beneficial organisms and the soil. For many years researchers have been looking for alternatives to reduce their use and /or replace them. Different carbonates have been investigated intensively in the last years. They are present in nature and were used in the past in organic farming. With Decree 404/2008, Annex II of Regulation (EEC) No. 2092/91 was updated and potassium bicarbonate (PBC) was included into the list of active substances allowed in organic farming. On 1 January 2009, potassium bicarbonate was also included into Annex I of Council Directive 91/414/EEC concerning the placing of plant protection products on the market.

Field trials carried out from 2003 to 2009 in South Tyrol evidenced an interesting efficacy of carbonate-based products against apple scab and other diseases, but also phytotoxic side effects emerged depending on the formulation and the applied rate. First results were presented in the proceedings of the 12th and 13th Ecofruit conference. The results of recent field trials are presented, which aimed at evaluating the efficacy of different carbonate-based products in stopping further apple scab development and thus their curative action.

Keywords: apple, apple scab, carbonate, organic orchards

Introduction

In the EC, for many years, almost exclusively copper- and sulphur-based products were allowed for the control of a variety of different fungal diseases in organic farming. It is well-known that these products can negatively affect the soil, beneficial organisms, etc. Depending on the climatic conditions during application, they can also cause severe damage on leaves and fruits. For many years, researchers have therefore been looking for valuable alternatives in order to reduce their use and/or even replace them.

Carbonates were brought forward frequently as alternatives to copper- and sulphur-based products (Grabler & Smilanick, 2001; Vecchione et al., 2002; Leeson & Crips, 2004; Smilanick et al., 2004; Conway et al., 2005; Tamm et al., 2006; Heyne et al., 2006; Pfeiffer 2008; Jamar et al., 2007). They are present in nature, and have already been used in the past in organic farming. They are considered harmless from an ecotoxicological and toxicological point of view (EPA, 1999). Since 2008 they are included into Annex II of Regulation (EEC) No. 2092/91 on organic production, and in 2009 potassium bicarbonate has also been included into Annex I of Council Directive 91/414/EEC concerning the placing of plant protection products on the market.

From 2003 to 2006, field trials with unformulated and formulated PBCs were conducted at the Research Centre Laimburg (South Tyrol, Italy) in order to evaluate their efficacy against apple scab and to record possible phytotoxic effects on the crop. Part of the results were published in the proceedings of the 12th and 13th Ecofruit-conference. (Kelderer & al

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2006 and 2008). Of great interest are the statements of Kunz (2008), who observed a curative effect of carbonates against apple scab on potted plants in greenhouse trials. Our studies carried out in 2008 and 2009, aimed at verifying the occurrence of a curative effect also in the open field.

Material and Methods

All trials were carried out in established apple cv Golden Delicous orchards under integrated pest management (rootstock: M9) at the Research Centre Laimburg (South Tyrol – Italy). In addition to the treatments against apple scab, common cultivation practices were used in all study orchards. The product name, its active substance, manufacturer/distributor, and the concentration of active substance in each product are listed in Table 1.

Table 1: description of the products tested in 2008 and 2009.

Product name	Active substance	% Active substance	Manufacturer/ distributor
Mycosin	Acid clay	-	Biofa
Cueva	Cu- octanate	18	Neudorff
Kocide 3000	Cu-hydroxide	15	DuPont
Armicarb*	K-bicarbonate (PBC)	85	H&I Agritech
Bicarbonato di potassio*	K-bicarbonate (PBC)	99	ACEF
Vitisan*	K-bicarbonate (PBC)	99	Biofa
Potassio carbonato	K-carbonate	98	ACEF
Polisolfuro di Calcio	Lime sulphur	23	Polisenio
Sodio bicarbonato	Na-bicarbonate	99	SISECAM
Tiovit Jet	Sulphur	80	Syngenta
Thiopron	Sulphur	83	Cerexagri

*unformulated K-bicarbonate

<u>Preventative applications with motorized sprayer during primary infection period (2008 and 2009)</u>

To compare the different treatments, a randomized complete block design with 4 replicates per treatment and with 7 trees per plot was used. To prevent border effects, each plot was bounded by guard trees and guard rows. Treatments were applied with a motorized sprayer for experimental trials from Waibl (transverse current blower), using a spray volume of 500 l water per hectare and m foliage height. Treatments were applied immediately before it began to rain on dry leaves from March to end of May. In 2008, the duration of leaf wetness during the major infection periods was extended using above-canopy irrigation.

<u>Scab stop applications with motorized sprayer during the period of primary infection (2008 and 2009)</u>

To compare the different treatments, a randomized complete block design with 4 replicates per treatment and with 7 trees per plot was used. To prevent border effects, each plot was bounded by guard trees and guard rows. Treatments were applied with a motorized sprayer for experimental trials from Waibl (transverse current blower), using a spray volume of 500 l water per hectare and m foliage height. Treatments were applied at 300 degree hours, followed by a second application after additional 600 degree hours in case of enduring leaf wetness. As a second variant, all four treatments were also applied only after 600 degree hours. The trials lasted from March to end of May.

Scab stop applications through above-canopy irrigation during primary infection period (2008 and 2009)

To compare the different treatments, a randomized complete block design with 3 replicates per treatment and with 10 plants per plot was used. Each plot was bounded by guard trees and guard rows to prevent border effects. All treatments were applied through above-canopy irrigation. To ensure uniform wetting and coverage of the vegetation within the plots, two full circle sprinklers (Kofler K10; throw distance: 12 m; nozzle size: 3 mm) with overlapping water jet were placed in each plot. In 2008, treatments were applied at 500 degree hours of leaf wetness. In case leaf wetness persisted for more than 650 degree hours, an additional application was made at 900 degree hours. In 2009, treatments were applied at 300 degree hours, and were repeated after additional 300 degree hours in case of enduring leaf wetness. Treatments were applied until the end of May.

Preventative applications with motorized sprayer during secondary infection period (2009)

This trial was carried out only in 2009. To compare the different treatments a randomized complete block design with 4 replicates per treatment and with 7 trees per plot was used. To prevent border effects, each plot was bounded by guard trees and guard rows. Treatments were applied with a motorized sprayer for experimental trials from Waibl (transverse current blower), using a spray volume of 500 l water per hectare and meter foliage height. The entire orchard was treated extensively during the primary infection period in order to establish high apple scab pressure during the secondary infection period. The orchard was treated on a weekly basis from the end of June until the end of August.

Assessments

In all trials the incidence of apple scab on leaves and fruits was assessed twice, at the end of the primary infection period and in autumn at harvest, respectively. In 2008, in addition, percent fruit russeting was assessed. In 2009, for the preventative applications during the secondary infection period, we also assessed for percent leaf drop (visual assessment according to a scale ranging from 0 to 10) and fruit russeting at harvest. To assess for fruit russeting, in each plot, at harvest, fruits were checked for symptoms of fruit russeting and classified according to a scale ranging from 0 to 10, with 0 = fruit with no russeting symptoms, 1 = fruit with russeting symptoms at stalk cavity, 2 = fruit with 10-20% fruit area affected by fruit russeting, and so on. The percentage of fruits with fruit russeting index above 3 was then calculated and indicated in the tables as % fruit russeting. In this trial, we also determined the proportion of spider mites vs predatory mites present at harvest, by counting the number of spider mites and predatory mites on randomly selected leaves.

Statistical analysis

All data were compared across treatments using 1-way ANOVAs followed by Student-Newman-Keuls' test for posthoc comparisons of means ($P<0.05$). To improve homoschedasticity, data expressed in percentages were arc sin (radq(x/100)) - transformed. All analyses were performed with the statistics programme PASW 17.

Results

Trial 2008: Preventative applications with motorized sprayer during primary infection period

Table 2: Percentage of leaves and fruits infected by apple scab and percent fruit russeting in the different treatments

Product	Applied rate (g/hl)	% affected leaves		% affected fruits		% fruit russeting [1]	
Kocide 3000	10 Cu met.	63.6	b	74.5	a	43.1	bc
Cueva	10 Cu met.	55.4	a	77.0	a	48.2	c
Mycosin	1000	79.5	c	94.5	ab	13.2	a
Armicarb	300	90.3	d	100.0	b	34.7	bc
PBC[2]	500	93.0	d	100.0	b	25.7	abc
PBC[2]	1000	91.7	d	98.5	ab	39.0	bc
PBC[2]	1500	89.4	d	97.5	ab	41.2	bc
PC[2]	1000	85.8	cd	97.0	ab	43.3	bc
NaBC[2]	1000	79.0	c	96.0	ab	22.2	ab
Polisenio	1500	59.4	ab	86.0	ab	19.0	a
Control	-	91.5	d	100.0	b	32.7	abc

[1] percentage of fruits with more than 30 % russeted fruit surface area

[2] not formulated

As mentioned above, the duration of leaf wetness during the major infection periods was extended using above-canopy irrigation, which resulted in extremely high disease pressure. In fact, in the untreated control almost all leaves and fruits were infested by apple scab (Table 2).

Disease incidence on leaves was significantly lower for the copper-based treatments (Kocide 3000 and Cueva) and for the standard Lime sulphur than for all the other treatments. On fruits, differences among treatments were even less marked. Fruit russeting was lowest on fruits treated with Mycosin and Lime sulphur.

Trial 2008: Scab stop applications with motorized sprayer during the period of primary infection

Table 3: Percentage of leaves and fruits infected by apple scab and percent severe fruit russeting in the different treatments

Product	DH[1]	Applied rate (g/hl)	% affected leaves		% affected fruits		% russeted fruits [2]	
Polisenio	300 + 600	1500	1,8	a	5,5	a	17,6	a
Polisenio	600	1500	4,8	a	17,5	ab	16,8	a
PBC + Tiovit[3]	300 + 600	1000 + 200	10,0	b	24,5	ab	14,0	a
PBC + Tiovit[3]	600	1000 + 200	12,8	c	51,5	bc	7,5	a
PC + Tiovit[3]	300 + 600	1000 + 200	7,7	b	42,9	bc	19,5	a
PC + Tiovit[3]	600	1000 + 200	9,1	b	46,4	bc	10,2	a
Mycosin + Tiovit	300 + 600	500 + 200	21,4	d	67,4	bcd	9,2	a
Mycosin + Tiovit	600	500 + 200	21,4	d	81,2	cd	10,3	a
Control	-	-	29,9	e	89,7	d	13,6	a

[1] Degree hours after onset of rain

[2] percentage of fruits with more than 30% russeted fruit surface area

[3] not formulated

Also in this trial, disease pressure was extremely high (90% fruits affected by apple scab in the untreated control; Table 3). The treatments had been applied on wet leaves at the degree hours (DH) after onset of rain indicated in Table 3. Best results were achieved with Lime Sulphur (Polisenio) applied at 300 DH after the onset of rain, with efficacy values of approximately 94.0% in reducing both disease incidence on leaves and fruits. Also when applied at 600 DH after the onset of rain, Lime sulphur provided good disease control. The two tested carbonate-based products (PBC and PC) showed only partial efficacy in suppressing apple scab.

Trial 2008: Scab stop applications through above-canopy irrigation during primary and secondary infection period

Table 4: Percentage of leaves and fruits infected by apple scab and percent fruit russeting in the different treatments

Product	**DH**[1]	**App. rate (g/hl)**	**% affected leaves**		**% affected fruits**		**% russeted fruits** [2]	
Polisenio	500+ 900	30	4,8	a	14,7	a	38,8	a
PBC + Tiovit[3]	500+ 900	22,5 + 4,5	20,1	c	52,0	a	49,9	ab
Mycosin + Tiovit	500+ 900	10 + 4,5	32,3	d	89,3	b	33,9	a
PC + Tiovit[3]	500+ 900	15	12,8	b	28,7	a	60,3	b
Control	-	-	34,0	d	94,0	b	43,6	ab

[1] Degree hours after onset of rain
[2] percentage of fruits with more than 30% russeted fruit surface area
[3] not formulated

Also when applied with the above-canopy irrigation system, Lime sulphur (Polisenio) provided effective disease control under conditions of high disease pressure (mean efficacy: 86.0% on leaves and 84.4% on fruits; Table 4), while lower efficacy values were obtainedwith the two carbonates.

Trial 2009: Preventative applications with motorized sprayer during primary infection period

Table 5: Percentage of leaves and fruits infected by apple scab in the different treatments

Product	**Applied rate (g/hl)**	**% affected leaves**		**% affected fruits**	
Polisenio	1500	27.9	ab	4.9	a
Thiopron	558	41.4	b	4.0	a
Tiovit	419	53.3	d	6.0	a
Kocide 3000 + Tiovit	10 Cu met. + 419	24.9	a	1.0	a
Vitisan[1] + Tiovit	1000 + 419	39.6	b	7.4	a
Mycosin + Tiovit	1000 + 419	32.1	b	2.5	a
Control	-	61.0	e	11.7	b

[1] not formulated

Differences among treatments applied preventatively with the motorized sprayer during the primary infection period, were less evident in 2009 than in 2008. Best disease control on leaves was recorded for the copper-based product Kocide 3000 (10 g pure copper/100 l), followed by Lime Sulphur (Polisenio), Tiovit applied in tank mixture with the acid clay Mycosin, and finally by the tank mixture Vitisan plus Tiovit. Disease incidence on fruits was significantly lower in treated than in untreated control plots, with differences among treated plots not being significant.

Trial 2009: Scab stop applications with motorized sprayer during the period of primary infection

Table 6: Percentage of leaves and fruits infected by apple scab in the different treatments

Product	DH[1]	Applied rate (g/hl)	% affected leaves		% affected fruits	
Polisenio	300 + 600	1500	29,1	ab	1,5	a
Polisenio	600	1500	39,7	bc	2,5	bc
Thiopron	300 + 600	558	48,8	c	8,2	c
Thiopron	600	558	45,2	c	6,1	c
Tiovit	300 + 600	419	50,0	c	6,4	c
Kocide 3000 + Tiovit	600	10 Cu met. + 419	45,4	c	2,5	bc
Kocide 3000 + Tiovit	300 + 600	10 Cu met. + 419	45,6	c	5,0	c
Vitisan[2] + Tiovit	600	1000 + 419	26,1	a	2,2	ab
Control	-	-	57,1	c	10,7	c

[1] Degree hours after the onset of rain

[2] not formulated

Also the results obtained in 2009 with curative applications with the motorized sprayer differed from those observed in 2008. Highest efficacy on leaves was recorded for unformulated PBC (Vitisan) and Lime sulphur (Polisenio), and similar results were obtained on fruits.

Trial 2009: Scab stop applications through above-canopy irrigation during primary infection period

Table 7: Percentage of leaves and fruits infected by apple scab in the different treatments

Product	DH[1]	Applied rate (g/hl)	% affected leaves		% affected fruits	
Polisenio	300	22,5	13,3	a	0,9	a
Thiopron	300	8,4	43,4	bc	13,8	bc
Tiovit	300	6,3	52,1	bc	14,3	bc
Vitisan[2] + Tiovit	300	15 + 6,3	35,6	b	3,3	ab
Control	-	-	57,1	c	26,5	c

[1] Degree hours after the begin of the rainfall

[2] not formulated

When the products were applied with the above-canopy irrigation, instead, the results recorded in 2009 confirmed those obtained in 2008: the efficacy of Lime sulphur (Polisenio) in reducing apple scab incidence on leaves amounted to 76.6%, while that of unformulated PBC (Vitisan) applied in tank mixture with Tiovit did not exceed 38%. However, both treatments provided comparable disease control on fruits.

Trial 2009: Preventative applications with motorized sprayer during secondary infection period

Table 8: Percentage of leaves and fruits infected by apple scab; percentage of leaf drop, proportion spidermites/predatory mites and percent severe fruit russeting in the different treatments

Product	Applied rate (g/hl)	% affected fruits		% leafdrop		spidermites/ predatory mites		russeting index	
Mycosin + Tiovit	800 + 223	15.1	ab	8.8	a	3.0	b	9.7	a
Ulmasud + Tiovit	800 + 223	12.6	ab	8.8	a	2.2	b	9.0	a
Rocksil + Tiovit	800 + 223	12.7	ab	10.0	a	1.2	a	9.1	a
Armicarb	300	13.2	ab	20.0	b	0.2	a	10.6	a
Vitisan[1] + Tiovit + TS Forte	600 + 223 + 200	11.3	a	26.3	b	0.2	a	10.9	a
Vitisan[1] + Tiovit	600 + 223	8.5	a	11.3	a	0.3	a	9.7	a
Thiopron	297	14.5	ab	11.3	a	0.4	a	10.6	a
Polisenio	800	9.5	a	10.0	a	0.4	a	11.1	a
Control	-	34.8	b	18.8	b	0.1	a	10.5	a

[1]not formulated

The highest paple scab incidence reduction with preventative applications during the secondary infection period was recorded for the tank mixture Vitisan + Tiovit, followed by the tank mixture Vitisan + Tiovit + TS Forte (Table 8). However, the latter treatment resulted in considerable leaf drop. A significant increase in the proportion spider mites/predatory mites was observed for the tank mixtures Mycosin + Tiovit and Ulmasud + Tiovit, but not for any of the other tested treatments. There was no significant difference between the treatments concerning the fruit russeting.

Discussion

The trials carried out in 2008 and 2009 aimed at comparing the efficacy of carbonate-based products in suppressing apple scab with that of reference products, commonly applied in organic orchards for apple scab control. We tested both preventative treatments and specifically targeted curative treatments. Treatments were either applied with a motorized sprayer or with the above-canopy irrigation system. In the two years of trials, results were not consistent, and to be considered conclusive, further studies are warranted. Possible explanations for these inconsistent results are provided below. Weather conditions in the two study differed considerably. In 2008 high and repeated rainfalls occurred. Furthermore, the duration of the major infection periods was extended with above-canopy irrigation, and disease pressure was therefore extremely high. Almost 100% apple scab incidence on leaves and fruits in the untreated control). When applied both preventatively and curatively, the efficacy against apple scab of the carbonate-based treatments was always considerably lower than that of the reference Lime sulphur treatment. In 2009, instead, relatively dry weather conditions occurred during the primary infection period. Higher than average spore flight took place during this infection period (17th, 20th, 27th and 30th of April). Furthermore, no heavy rainfalls occurred during the primary infection period. Ninety percent of the apple scab spots on leaves originated from this infection period (64,3mm). Since the leaves dried immediately, it was impossible to apply the treatments onto wet leaves, as originally planned. The carbonate-based treatments and the standard Lime sulphur provided similar results in both the preventative trials (primary and secondary infection period) and in those where treatments were specifically targeted with the motorized sprayer, while they did not when treatments were applied with above-canopy irrigation. In this case, the efficacy of Lime sulphur was considerably higher than that of the carbonates. Differences between 2008 and 2009 existed also in the amount of sulphur added to the tank mixtures. In 2009, in the preventative trials, the carbonates were applied in tank mixture with a sulphur-based product, but not in 2008, and the amount of sulphur added to the tank mixture in 2009 in the curative trials was much higher than that used in 2008. Previous studies with Armicarb (Kelderer et al. 2006 and 2008) have shown that formulation can definitely affect the efficacy of the product.

Given the results obtained in our trials under different climatic conditions and with the different product combinations, the following assertions can be made:

An appropriate formulation is an essential condition for the efficacy of carbonates, and, apparently, by adding a sulphur-based product at a high rate this requirement can be met. The efficacy of other tank mixtures must still be evaluated.

The addition of oily substances may result in increased leaf drop and fruit russeting (Table 8).

Carbonates must reach the leaves at an adequate rate. When applied during rainfall or with above-canopy irrigation, the active substance retained on the leaves is not enough to ensure effective disease control. To deepen our knowledge on this aspect, dose-response studies for preventative and curative applications in comparison to Lime sulphur are needed.

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