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Formulated and unformulated carbonates to control apple scab (*Venturia inaequalis*) on organic apple

Markus Kelderer[1], Claudio Casera[1], Lardschneider Ewald[1]

Abstract

In the EC at the moment only copper- and sulphur-based products are 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. Bicarbonates have been brought forward for many years. They are present in nature and were used in the past in organic farming. Up to now, in the EC, carbonates have not been included in the list of active substances, which may be used as plant protection products. A good chance exists that this will change in the future, which would open the possibility to apply for the inclusion of potassium hydrogen carbonate in Annex II B of regulation EEC 2091/92. Field trials carried out in 2006 and 2007 in South Tyrol evidenced an interesting efficacy of potassium hydrogen carbonate-based products against apple scab and other diseases, but also phytotoxic side effects emerged.

Keywords: apple, apple scab, carbonate, organic orchards

Introduction

In the EC, at the moment almost exclusively copper- and sulphur-based products are 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 fruit. For many years, researchers have therefore been looking for valuable alternatives in order to reduce the use of and/or even replace these products.
Hydrogen 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). 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). However, up to now, in the EC hydrogen carbonates have not been included in the list of active substances, which may be used as plant protection products. Within the harmonised framework of the regulation of plant protection products in the EC, a manufacterer has applied for the inclusion of potassium hydrogen carbonate (PBC) in Annex I as a new active ingredient, and therefore in the future it may be possible to apply for the inclusion of this active substance also in Annex II B (list of active substances, which may be used as plant protection products in organic farming). In 2006 and 2007, field trials were conducted in South Tyrol with unformulated and formulated PBC (Armicarb) in order to evaluate its efficacy against apple scab and to record possible phytotoxic effects on the crop.

[1]VZ-Laimburg, 39040 Post Auer, Italien; e-mail: Markus.Kelderer@provinz.bz.it (corresponding Autor)

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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.

Trial 2006: Scab stop applications through above-canopy irrigation during primary and secondary infection period

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. Treatments were applied up to 300 degree hours of leaf moisture after the beginning of the rain. From the 1st of June, the application rate of the lime sulphur-based product and PBC was reduced by one third.

Trial 2006: Preventive applications with motorized sprayer during primary and secondary infection period

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. Applications were repeated at 7-day intervals.

Trial 2006: Preventive applications with motorized sprayer during secondary infection period

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. The entire orchard was treated extensively with sulphur (200g/hl) 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 May until the end of August.

Trial 2007: Scab stop applications with motorized sprayer during the period of primary and secondary infection

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 up to 300 degree hours of leaf moisture after the beginning of the rain. During the period of highest infection risk (according to the apple scab simulation programme RimPro, April 30 to May 1), treatments were applied 650 degree hours after the beginning of the rain. From the 1st of June the application rate of lime sulphur was reduced to 800 ml.

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Trial 2007: Preventive applications with motorized sprayer during secondary infection period

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. The entire orchard was treated extensively with sulphur during the primary infection period in order to establish high apple scab pressure during the secondary infection period. The orchard was treated at 14-day intervals from the end of May until the end of August.

Data assessment and statistical analysis

The incidence of apple scab on shoots and fruits was assessed twice, at the end of the primary infection period and in autumn at harvest, respectively. Furthermore, at harvest we also assessed for leaf drop (visual assessment according to a scale ranging from 0 to 10) and fruit russeting. All data were compared using one-way ANOVAs, followed by the Tukey test for posthoc comparison of means ($P<0.05$). All analyses were performed with the software package SPSS 12.0 for Windows.

Results

Trial 2006: Scab stop applications through above-canopy irrigation during primary and secondary infection period (Table 1)

At the end of the primary infection period, in the untreated control plots the majority of shoots was infected by apple scab. The treatments Lime Sulphur and Armicarb showed good efficacy in reducing shoot infection, while Ca-hydroxide and vinegar were less effective. Almost no apple scab was observed on fruits after the primary infection period, but at harvest fruit infection amounted to 36 % in the untreated control plots. Low fruit infection levels were recorded on fruits treated with Lime Sulphur and Armicarb. In all plots, especially in those treated with formulated PBC, part of the fruits showed severe fruit russeting.

Table 1: Percentage of shoots and fruits infected by apple scab, percent severe fruit russeting, and leaf drop index in the different treatments

Treatment	Product	Applied rate (kg /ha)[1]	% infected shoots[2]	% infected fruits[3]	% severe fruit russeting[4]	Leaf drop index[5]
Lime Sulphur	Calcium	30	7.2 a	2.3 a	2.1 a	1 a
K-hydrogen carbonate	Armicarb	12	4.3 a	2.2 a	62.3 c	0 a
Ca-hydroxide	Calce fiocco	7,5	40.1 b	10.5 bc	5.3 a	7 b
Vinegar	Aceto Scaligero	150	34.5 b	28,3 c	23.5 b	8 b
Untreated control	-	-	81.6 c	36,0 c	14.3 b	9 b

[1] The application rate of Lime Sulphur and PBC was reduced by one third from June 1, 2006 on.
[2] Assessment at the end of the primary infection period
[3] Assessment at harvest
[4] % severe fruit russeting = percentage of fruits with more than 30 % russeted fruit surface area
[5] visual assessment according to scale ranging from 0 to 10; 10 = completely defoliated tree

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Trial 2006: Preventive applications with motorized sprayer during primary and secondary infection period (Table 2)

At the end of the primary infection period, in the untreated control one third of the shoots was infected by apple scab, while fruits basically did not show any symptoms of infection at both the end of the primary infection period and harvest. Armicarb, Cu-hydroxide, Lime Sulphur and und K-carbonate showed highest efficacy in reducing shoot infection. Differences among treatments in the number of predatory mites/leaf (assessed in July) failed significance. Formulated PBC, Cu-hydroxide, and, to a lower though considerable extent, unformulated K-carbonate caused severe fruit russeting.

Table 2: Percentage of shoots infected by apple scab, no. predatory mites/leaf and percent severe fruit russeting in the different treatments

Treatment	Product	Applied rate (g/hl)	% infected shoots[2]	No. Predatory mites/leaf[3]	% severe fruit russeting[4]
Lime Sulphur	Calcium	1000	1.2 a	1.3 a	15.1 a
Sulphur	Tiovit	288	7.3 b	1.6 a	11.3 a
K-hydrogencarbonate	Armicarb	600	0.0 a	0.9 a	67.3 c
Ca-hydroxide	Calce fiocco	500	16.5 bc	2.3 a	15.8 a
Cu-hydroxide	Kocide 2000	20 Cu met.	0.0 a	1.9 a	56.7 c
K-hydrogencarbonate[1]	K-bicarbonicum	510	7.5 b	1.8 a	19.6 a
K-carbonate[1]	K-Carbonicum	510	1.6 a	2.5 a	30.7 b
Na - hydrogencarbonate[1]	Na-bicarbonicum	510	3.7 ab	1.9 a	14.2 a
Untreated control	-	-	28.8 c	2.3 a	13.9 a

[1] unformulated Carbonates
[2] assessment at the end of the primary infection period
[3] Leaf-washing method according to Boller
[4] assessment at harvest: % severe fruit russeting = percentage of fruits with more than 30 % russeted fruit surface area

Trial 2006: Preventive applications with motorized sprayer during secondary infection period (Table 3)

The entire orchard was treated extensively with Sulphur (200 g/hl) during the primary infection period in order to establish high apple scab pressure during the secondary infection period. At harvest, no striking differences among the treatments in the percentage of infected leaves emerged, with the Armicarb- and Lime Sulphur-treated plots showing the lowest infection level. Differences among treatments in the percentage of infected fruits, instead, were more evident. The percentage of fruit infection was 63.2 % in the untreated control. Armicarb and the reference products Lime Sulphur and Cu-hydroxide showed highest and comparable efficacy in reducing fruit infection. Even though fruit russeting is not very likely to occur in the summer, some treatments caused fruit russeting, and the most severe effects were recorded in the plots treated with the products Armicarb, Lentus and Kocide 3000, respectively. It is known that the Golden Delicious is susceptible to leaf drop in the summer. Leaf drop was reduced in some of the treated plots, particularly in those treated with Armicarb, Calcium, and Lentus.

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

Treatment	Product	Applied rate (g/hl)	% infected leaves[2]	%infected fruits[3]	severe fruit russeting[4]	Leaf drop index[5]
Bacillus subtilis	Serenade	400	87.3 b	38.0 b	5.7 a	4 b
K-hydrogencarbonat	Armicarb	510	60.1a	11.0 a	18.3 c	1 a
Schwefelkalkbrühe	Calcium	800	67.2a	22.2 ab	4.3 a	1 a
Kalziumhydroxid	Calce fiocco	500	88.1 b	41.2 b	6.4 a	3 b
K-hydrogencarbonat[1]	K-bicarbonicum	510	82.0 b	32.3 b	6.3 a	3 b
Na-hydrogencarbonat[1]	Na-bicarbonicum	510	88.1 b	48.0 b	5.7 a	3 b
K-carbonat[1]	K-carbonicum	510	78.0 ab	38.2 b	4.2 a	3 b
K-carbonat	Lentus	1000	80.0 b	41.3 b	17.2 c	2 a
Cu-hydroxid	Kocide 3000	20 g Cu met.	80.0 b	25.0 ab	10.3 b	6 c
Kontrolle	-	-	88.2 b	63.0 c	1.2 a	5 c

[1] Unformulated carbonates
[2] Assessment at harvest
[3] Assessment at harvest
[4] % severe fruit russeting = % fruits with more than 30% russeted fruit surface area
[5] visual assessment according to scale ranging from 0 to 10; 10 = completely defoliated tree

Trial 2007: Scab stop applications with motorized sprayer during the primary and secondary infection period (Table 4)

As already mentioned above, in the period of highest primary infection risk, treatments were applied extremely late, and therefore at the assessment conducted in June the efficacy of most of the treatments in reducing percent leaf shoot infection was low. Best results were obtained with Lime Sulphur and K-carbonate. In autumn, fruit infection was highest in the untreated control plots (51,7 %), while it was lowest in the plots treated with Cu-hydroxide and Lime Sulphur (ca. 1%). Armicarb applications again resulted in severe fruit russeting. Leaf drop was rather limited in the study orchard. However, Cu-hydroxide considerably increased leaf drop.

Table 4: Percentage of shoots and fruits infected by apple scab, percent severe fruit russeting, and leaf drop index in the different treatments

Treatment	Product	Applied rate (g/hl)[2]	% infected shoots[3]	% infected fruits[4]	% severe fruit russeting[5]	Leaf drop index[6]
K-hydrogencarbonate	Armicarb	500	33.1 ab	4.6 b	52.1 b	1 a
K-hydrogencarbonate	Armicarb	300	33.7 ab	8.2 bc	31.2 ab	1.2 a
K-hydrogencarbonate	Armicarb	100	41.8 b	23.1 c	28.2 ab	1.2 a
KHC+Sulphur	Armicarb + Tiovit	100 + 200	36.1 b	10.1 bc	22.1 ab	1.2 a
Lime sulphur	Calcium	1500	23.7 a	1.4 a	26.7 ab	1 a
Sulphur	Tiovit	200	33.2 ab	10.5 bc	17.3 a	1.2 a
K-carbonate[1]	K-carbonicum	500	21.5 a	8.7 bc	24.1 ab	2.5 b
Na-hydrogencarbonate[1]	Na-bicarbonicum	500	40.1 b	5.8 b	21.1 ab	2.5 b
K-hydrogencarbonat[1]	K-bicarbonicum	500	43.0 b	10.2 bc	15.2 a	2 b
Cu-hydroxide	Kocide 3000	10 g Cu met.	39.1 b	0.7 a	24.8 ab	4.5 c
Untreated control	-	-	541 c	51.7d	21.3 ab	2.8 b

[1] Unformulated carbonates
[2] The application rate of Lime Sulphur and Armicarb was reduced by one third from June 1, 2007 on.
[3] Assessment at the end of the primary infection period
[4] Assessment at harvest
[5] % severe fruit russeting = % fruits with more than 30% russeted fruit surface area
[6] visual assessment according to scale ranging from 0 to 10; 10 = completely defoliated tree

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Trial 2007: preventive applications with motorized sprayer during secondary infection period (Table 5)

The entire orchard was treated extensively with sulphur during the primary infection period in order to establish high apple scab pressure during the secondary infection period. At harvest, no significant differences among treatments in shoot infection were registered. Applications of Kocide 3000 at a rate of 20 g copper/hl, the acid clay Mycosin (1000 g/hl), and Lime Sulphur evidenced highest efficacy in reducing fruit infection. The acid clay-based products Ulmasud and Mycosin reduced fruit russeting, while all the other treatments slightly increased fruit russeting. Leaf drop was observed only on trees treated with copper-based products.

Tab. 5: Percentage of fruits infected by apple scab, percent severe fruit russeting, and leaf drop index in the different treatments

Treatment	Product	Applied rate (g/hl)	% infected fruits[1]	% severe fruit russeting[2]	Leaf drop index[3]
Acid clay	Ulmasud	1000	24.9 b	12.3 a	0 a
Acid clay	Mycosin	1000	15.1 a	9.3 a	0 a
Acid clay	Mycosin	500	20.0 ab	11,2 a	0.2 a
K-hydrogencarbonate	Armicarb	300	32.1 c	31.0 c	0.7 a
K-hydrogencarbonate	Armicarb	400	27.1 c	33.2 c	0.5 a
K-hydrogencarbonate	Armicarb	500	24.7 b	26.1 c	0.5 a
Lime sulphur	Polisolfuro	800	18.0 ab	25.9 c	0 a
Cu-hydroxide	Kocide 3000	10 g Cu met.	29.1 c	28.1 c	2.2 b
Cu-hydroxide	Kocide 3000	20 g Cu met.	14.3 a	24.1 c	3.7 c
Bordeaxmixture	Poltiglia bordolese	20 g Cu met.	23.1 b	27.8 c	2 b
Untreated control	-	-	31.8 c	18.9 b	0.2 a

[1] Assessment at harvest
[2] % severe fruit russeting = % fruits with more than 30% russeted fruit surface area
[3] visual assessment according to scale ranging from 0 to 10; 10 = completely defoliated tree

Discussion

In South Tyrol, the first trials with unformulated K-hydrogen carbonate as well as with the formulated commercial K-hydrogen carbonate-based product Armicarb were carried out in 2003 and 2004. The trials aimed at suppressing apple scab in organic farming. However, results were not conclusive (Kelderer et al., 2006), and therefore additional trials were conducted in 2006 and 2007. The efficacy in reducing apple scab of both scab stop and preventive applications of different formulated carbonates (Armicarb and Lentus) and unformulated carbonates (K-hydrogen carbonate, Na-hydrogen carbonate, and K-carbonate, respectively) with above-canopy irrigation and common spray equipment during the primary and secondary infection period was investigated. All trials were performed on apple cv. Golden Delicious, because this variety, particularly susceptible to apple scab and fruit russeting, is the most common variety in South Tyrol. In addition to leaf and fruit infection, special care was also taken in assessing possible phytotoxic effects (fruit russeting and leaf-burn) and other side effects (side effects on predatory mites and leaf drop). The K-hydrogen carbonate-based product Armicarb, applied at a rate of 7.5 – 12 kg/ha both preventively and targeted during the primary and secondary infection period, showed very good efficacy in controlling apple scab, comparable to that of the reference product Lime Sulphur. Also at lower application rates the product still showed good efficacy. However, in several trials Armicarb caused severe fruit russeting.

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In these field trials we did not observe any leaf-burn, as noticed in other studies (Rühmer, pers. comm., 2007); on the contrary, in some cases a reduction in leaf drop was recorded. Unformulated carbonates were not as effective as Armicarb in controlling apple scab, but caused almost no fruit russeting.

Acknowledgements

This project was supported by the Italian Ministry of Agriculture and forestry (Mipaaf) (D.M. 91516 del 15/09/05, Studi finalizzati ad ottemperare alle limitazioni sui quantitativi di rame o mediante l'impiego di formulazioni a basso dosaggio o con l'adozione di mezzi alternativi)

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