Successful blossom thinning and crop regulation for organic apple growing with potassium-bi-carbonate (Armicarb®): Results of field experiments over 3 years with 11 cultivars

F.P. Weibel[1], B. Lemcke[1], U. Monzelio[1], I. Giordano[1] B. Kloss[2]

Abstract

With field trials over 3 years in a commercial organic orchard in Switzerland we have tested the efficacy of Armicarb® (potassium-bi-carbonate) for flower thinning in organic apple production. Over time, Armicarb was tested on 11 cultivars, at different application periods, in different concentrations, and always in comparison to other agents that are already allowed for thinning in organic fruit production in the European Union as e.g. lime sulphur, molasses, mechanical rope-thinner or combinations of methods. Armicarb proved to be an efficient and reliable thinning agent with an efficacy similar to the now recommended methods with rope device, molasses or lime sulphur but has the advantage to be an environmentally very friendly product. On the other hand, the risk for fruit russeting is comparably elevated especially with cultivars Elstar, Golden Del. and Gala. Finally, we have elaborated cultivar-specific recommendations for the use of Armicarb for thinning purposes, which were the basis for the Swiss Federal approval to use Armicarb for thinning in conventional apple production in 2011. Its approval for thinning purposes for Swiss organic apple production is expected for the season 2012.

Keywords: apple, organic, thinning, crop regulation, potassium-bi-carbonate

Introduction

One of the main challenges in organic apple growing is the regulation of the crop load to, i) prevent bi-annual bearing, ii) improve fruit quality, and iii) save labour costs for manual thinning. Up to now, there are only few methods and agents allowed for certified organic agriculture: e.g. the mechanical rope thinner device (Bertschinger *et al.,* 1998). After Weibel *et al.* (2008), however, 1-2 treatments with the rope thinner alone seldom provide a satisfying result and should be combined with a desiccant agent such as e.g. molasses. Also with 2-3 molasses treatments during flowering period, for rewarding results a combination with the rope device is recommended by the latter authors. In most EU countries lime sulphur is the standard thinning agent. At dosages of 2-2.5 vol.% and 2-3 treatments over flowering period it provides a fairly good efficacy, and induces no risk for fruit russeting. In Switzerland, however, lime sulphur is not registered by the Federal authorities because of its potential human toxicity.

For the use as a contact fungicide Armicarb (potassium bi-carbonate; $KHCO_3$) is already licensed for organic apple production. The active component is 85% potassium-bi-carbonate which acts on fungi by changing the pH and the osmotic pressure plus the direct ionic effect of potassium-bi-carbonate on the cell walls (Stähler Suisse SA, Zofingen, CH). After promising pre-trials in 2006 and 2007 to apply Armicarb also for crop regulation, we conducted from 2009-2010 replicated thinning trials with several cultivars under very close to praxis conditions (e.g. using a commercial orchard sprayer). The main questions to answer were: i) thinning effect of Armicarb in comparison to other methods; ii) thinning

[1] Research Institute of Organic Agriculture (FiBL); CH-5070 Frick; franco.weibel@fibl.org
[2] B. Kloss, Master Student 2009 at University Stuttgart-Hohenheim (Dept. Horticulture; Prof. J. Wünsche)

effect and negative side effects (e.g. phytotoxicity) of Armicarb with different cultivars; iii) optimal concentration for different cultivars; iv) optimal application period and frequency. For this publication, we display and discuss mainly the results related to Armicarb.

Material and Methods

The field trials were conducted on the commercial organic fruit farm of family Ch. Vogt at Remigen. Situated at the edge of the eastern Swiss Jura mountains, 450 m above sea level; av. temp. 9.1 °C/y; av. rainfall 900 mm/y; soil is a pseudo-gleyic, medium-deep brown soil of 18.9% clay, 45.8% silt and 35.1% sand, pH(H_2O) is 5.5-5.9.

The experiments were performed in 2008, 2009 and 2010; the last return-to-bloom assessment was in April 2011. Per cultivar, there were usually 3, minimum 2 replicated plots randomly distributed. A plot consisted of usually 18-27 trees (minimum 9). Most trees were on rootstock M9 (except Maigold M27, and Topaz M27 in 2009); in full production age between 7 and 18 years old; spaced 1 x 3 m and under a hail protection net. Usually 10, minimum 5 representative trees per plot were selected as measuring and counting trees. Flowering intensity of the trees used for the experiment was at least 75% but mainly 90-100%. Usually the products were applied with a commercial orchard sprayer (Lochmann RPS) using 1000 L water per ha; case-wise a motor backpack sprayer (Birchmeier M155) was used. Usually the test agents were applied twice during flowering stage F and F_2 (BBHC 61-65); 3 applications were occasionally necessary when flowering period was long. The rope device was applied at pre-bloom at stage red tip (E, BBCH 57) at high driving speed (9-11 km/h) in order to keep physical damages to leaves and branches as low as possible. Because the agents tested (Tab. 1 Armicarb treatments, Tab. 2 other agents and methods) are all desiccants, we applied them at warm days (around 20 °C at midday) with no rain announced for the following 24 h, and when a maximum of un-pollinated flowers were open, thus, spraying time began from 9-10 a.m. on. For the rope device, however, we aimed for colder, cloudy weather to enhance the physiological shock of the treatment (according to Weibel *et al.,* 2008).

Fruit set was counted before and after June drop: from each measuring tree 4-6 representative branches in the centre zone of the canopy were chosen Over the entire length of each branch the amount of fruit clusters and the number of fruits per cluster (0,1, 2, 3+) was counted using a multiple hand counter tally. Russeting was assessed as % incidence; when treatment-induced russeting seemed to be more intensive, we also assessed severity as percentage of affected fruit skin. Few days before harvest final fruit set was estimated as percentage from an optimal crop load (set as 100%); and 25 representative fruits per replicated plot were collected to assess fruit diameter and wight of the fruits. To assess the treatments' influence on bi-annual bearing, return to bloom was counted in mid April of the following year as percentage of flower buds of total buds.

For statistical analysis we used ANOVA models (treatment, cultivar, replicated block (nested with cultivar) and interaction cultivar*treatment). For multipe treatment comparison a post ANOVA Tukey test was performed ($p<0.05$; JMP V. 8.0.1, SAS Inc.).

Table 1: Variants tested with Armicarb from 2008-2010 (beside untreated control and hand thinning of 2/3 of the flower clusters).

Year	Application frequency and timing	Concentrations (kg/ha)	Cultivars
2008	3 x during flowering period (F-F_2, BBHC 61-65)	5, 10, 15, 20	Golden Del., Idared, Elstar, Maigold,
2009	1 x at F(61) or F_2(63) or F_2(64) or F_2(65) or at T-stage	20, 15 at T-stage	Topaz, Otava (both scab resistant)
	2 x at F(61) and F_2(65)	10, 15, 20	Golden Del., Gala Elstar, Maigold, Topaz (M9), Topaz (M27), Otava
2010	2 x at F(61) and F_2(65)	15	Golden Del., Braeburn, Pinova, Gravensteiner, Topaz, Otava, Ariane (scab resistant)
	2 x at F(61) and F_2(65)	20	Maigold
	2 x at F(61) and F_2(65) combined with rope thinner	15	Elstar, Topaz

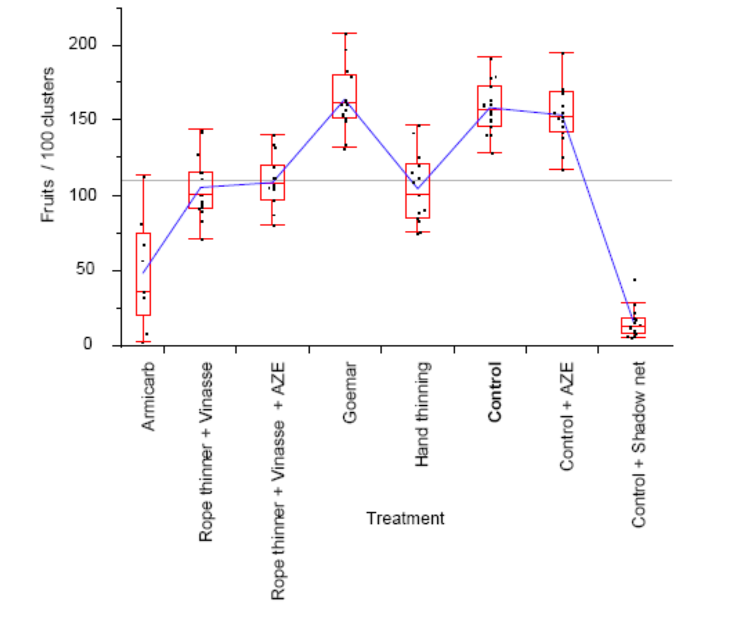
Table 2: Treatments tested in comparison to Armicarb from 2008-2010 (beside untreated control and hand thinning of 2/3 of the flower clusters).

Product	Description	Application
Rope device	"Gessler" (Friedrichshafen, DE), 286 Nylon ropes of 50 cm length on a 2 m vertical axis with 300 rev./min.	1-2 at stage E(BBHC 57) at 9-11 km/h driving speed
Shadow net	"AGROFLOR" (Nendeln, FL) with 74% light reduction	for 3-5 days 20 days after full bloom
Lime sulphur	Ca-Polysulphid 381g/L "Polisenio", IT	2.5 vol%; 2-3 x during flowering period (F-F_2, BBHC 61-65)
Vinasse Also in combination with rope device application (see above)	Molasses from sugar beet "Bioorga-NK-flüssig" (60 g N/L, 70 g K/L); Hauert HGB Dünger AG, Switzerland	5-7 vol.%; 2-3 x during flowering period (F-F_2, BBHC 61-65)
Acetic Acid	"Apfelessig" for cooking purposes with 5 g AA/L (Bio Farm, Switzerland)	3 vol %; 2-3 x during flowering period (F-F_2, BBHC 61-65)
"Black oil"	Self made mixture of pine oil (NuFilm 1ml/L) and dust of active carbon (25 g/L) to induce a micro-shading of the flower clusters by the black colour	2-3 x during flowering period (F-F_2, BBHC 61-65)
Goemar®	An algae substrate containing natural GA 14 and micro-nutirents, Stähler Suisse SA, Zofingen, CH	0.3 vol.% 2-3 times during flowering period (F-F_2, BBHC 61-65)

Results

Experiments in 2008

Figure 1 shows example-wise the thinning effects counted before June drop in 2008 on cv. Elstar. The treatments effects were similar but less expressed in the parallel trials on cv. Idared. Armicarb (in that year at a dosage of 20 kg/ha) had a strong, in this case almost too radical thinning effect by decreasing the fruit set from 159 fruits per 100 flower clusters (FlCl) to 49. This corresponds to a thinning effect of 69.4 %. Like this, the Armicarb treated trees had only half of the fruit set compared to hand thinning (removal of 2/3 of the flower clusters) and the organic standard treatment rope-device plus vinasse, both showing thinning effects of 33 %. Net-shadowing caused a far too intensive fruit drop down to only 16 fruits/100 FICl remaining.



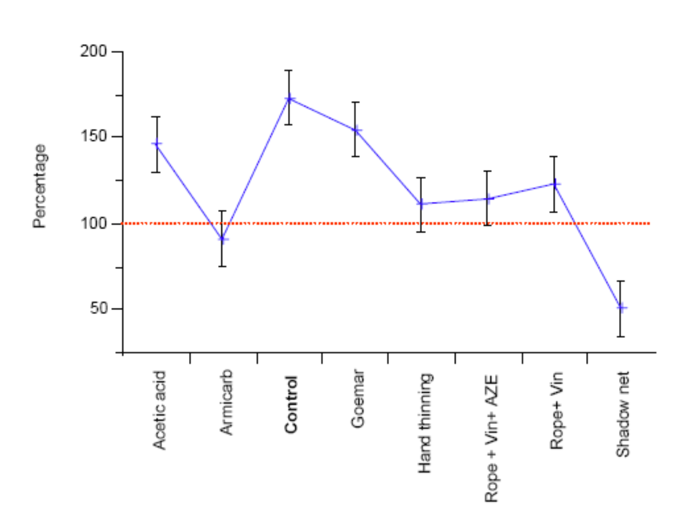
Tukey HSD Test

Treatment				*Mean*
Goemar	A			164.0
Control	A			159.1
Control + AZE	A			154.0
Rope thinner + Vin + AZE		B		109.3
Rope thinner + Vin		B		105.7
Hand thinning		B		104.7
Armicarb			C	48.7
Control + Shadow net			C	16.0

Levels not connected by same letter are significantly different. LSD = 43.37

Figure 1: Number of fruits/100 clusters with cv. Elstar under 8 different thinning treatments counted before June drop in 2008. Represented are Box Plots with the great mean line (horizontal line). AZE = acetic acid. Vin = vinasse, LSD = least significant difference

The effect of the treatments on crop load before harvest in 2008 can be seen in Figure 2: the untreated control was clearly over loaded with 173.3 % of an optimal crop load; Armicarb treated trees were slightly over-thinned showing 91.7 % of an optimal crop load, shadow nets clearly over-thinned to only 51.7 %, meanwhile the positive control treatments like hand thinning and rope device plus vinasse were between 112 and 123 %; Goemar and Acetic Acid had no effect.



Tukey HSD-Test ($p < 0.05$)

Treatment						*Mean %*	*SD*
Control	A					173.3	5.8
Hand thinning			C	D		111.7	7.6
Goemar	A	B				155.0	13.2
Acetic acid (AZE)	A	B	C			146.7	25.2
Rope thinner + Vin		B	C	D		123.3	5.8
Rope thinner + Vin+ AZE			C	D		115.0	13.2
Armicarb				D		91.7	10.4
Shadow net					E	51.7	12.6

Levels not connected by same letter are significantly different. LSD=37.02

Figure 2: Percentage of optimal fruit load (visually estimated) before harvest with cv. Elstar. Dotted line = optimal fruit load (100%). Vin = vinasse, AZE = acetic acid. LSD = least significant difference.

As a consequence, fruit weight of Armicarb treated trees increased by 25. 2 % from 130 g/fruit in the untreated control to 174.3 g/fruit. Return to bloom in the Armicarb treated Elstar plots in the following year with 89.6 % flower buds was clearly higher, almost too high, compared to hand thinning and rope device plus vinasse with only 7-23 % flowering buds whereas untreated control developed only 0.9 % of flower buds (data per treatment not shown in detail).

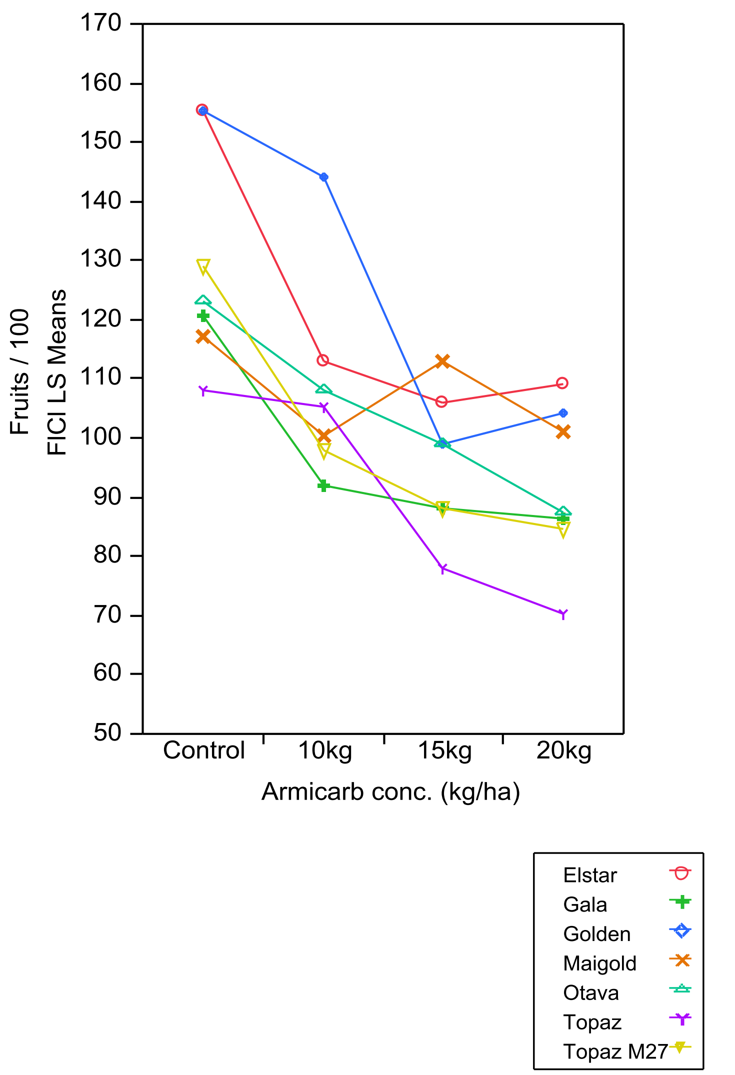
The trials with different Armicarb concentrations in 2008 with cv. Golden Delicious, Idared, Elstar and Maigold revealed that concentrations must be between 10-20 kg/ha. The results showed a tendency that with most cultivars 5 kg have almost no thinning effect, 15 kg/ha are significantly more effective than 10 kg/ha, but 20 kg/ha do not further improve the thinning effect compared to the 15 kg/ha concentration. Furthermore, the incidence of fruit russeting - mainly with Elstar - increased at 15 and 20 kg/ha (data not shown in detail, see results 2009).

Experiments in 2009

In 2009 the experiments on different Armicarb concentrations were repeated with 10, 15 and 20 kg/ha on cv. Gala, Golden Delicious, Elstar, Maigold, Topaz (M9, scab resistant), Topaz (M27) and Otava (scab resistant). The results confirmed that a relevant thinning effect can be achieved only from 15 kg/ha on. This trend was obvious for all cultivars tested. In that year, the thinning effect by 15 kg/ha Armicarb as it was assed before June drop was around 40 % with Topaz on M9 and M27 and Elstar, around 30 % with Maigold and Otava but only 2 % with Golden D (data not shown). After June drop (Fig. 3), Golden D. 'catched up' to a thinning effect of 30%, similar to Elstar, Gala and Topaz (M9 and M27); with Maigold, due to a high natural June drop, only a 9.4 % thinning effect resulted at this date. With most cultivars the 15 kg/ha Armicarb concentration led to a close to optimal crop load before harvest. Exceptions were Maigold, where a concentration of 20 kg/ha gave a better final result without a concerning increase of russeting. In this year, especially with Elstar, Gala and Golden Del. the 15 kg/ha dosage of Armicarb increased the incidence of fruits affected with russeting in a magnitude of 10-17 %.

The data on return to bloom as percentage of flower buds in the following year (2010) did not reveal significant treatment effects except for Otava with an increase of 61% flower set. Nevertheless, in the plots treated with 15 kg/ha Armicarb, crop load before harvest in 2010 was improved towards optimal fruit set in the magnitude of 9 % (Elstar and Otava) to 34 % (Topaz) (data not shown in detail).

In the separate trial to test different timing of Armicarb with cv. Topaz and Otava with only a single application, we could see that the thinning effect of later Armicarb applications at stage F_2 65 is superior (22 %) than with earlier applications at stage F_2 61 or 62 or 63 (8.2 %). The reason for this pattern is that the later the more flowers are open and affected by the agent. Also the incidence of russeting increased with later applications from 4 % at F_2 62 up to 10% at F_2 65. Russeting damages were particularly severe - reaching 22 % incidence - in the case where 20 kg/ha Armicarb were applied on Topaz at late flowering stage F_2 65 shortly before it began to dizzle with rain. We assume that under these circumstances Armicarb got entirely in solution and too intensively into contact with the fruit epidermis. The data of the timing trial are not shown in detail.



Cultivar and Armicarb conc. kg/ha	Fr/100 FrCl	Diff. to Control %	% of opt. crop load	Russet. incid. %	Fruit weight g
Elstar, 10kg	112.8	24.0	125	15	102
Elstar, 15kg	105.8	28.7	108	17	120
Elstar, 20kg	109.1	26.5	110	20	128
Elstar, Contr.	148.4	0	135	0	99
Gala, 10kg	92.0	20.3	110	5	117
Gala, 15kg	88.2	23.6	100	10	121
Gala, 20kg	86.2	25.5	100	13	124
Gala, Contr.	115.4	0	115	0	116
Golden, 10kg	143.9	-1.4	105	5	-
Golden, 15kg	99.0	30.2	105	10	-
Golden, 20kg	104.3	26.5	105	15	-
Golden, Contr.	141.9	0	100	0	-
Maigold, 10kg	100.3	14.3	120	3	-
Maigold, 15kg	106.1	9.4	120	5	-
Maigold, 20kg	101.2	12.6	107	7	-
Maigold, Contr.	117.0	0	130	0	-
Otava, 10kg	108.0	12.3	115	2	106
Otava, 15kg	99.0	19.6	100	8	112
Otava, 20kg	87.3	29.2	105	10	118
Otava, Contr.	123.2	0	110	0	94
TopazM9,10kg	105.1	2.6	103	3	99
TopazM9,15kg	78.0	27.7	95	6	113
TopazM9,20kg	70.3	34.8	88	12	116
TopazM9,Contr	107.90	0	108	0	104
TopazM27,10kg	98.0	24.0	108	5	106
TopazM27,15kg	88.1	31.7	103	8	107
TopazM27,20kg	84.7	34.3	103	10	108
TopazM27,Contr	128.9	0	112	0	91

Figure 3: Armicarb concentration trials in 2009 with cv. Elstar, Gala, Golden D., Maigold, Otava, Topaz (on rootstocks M9 and M27) with 0, 10, 15 and 20 kg/ha Armicarb in 1000L water 2 x during bloom: Number of fruits per 100 flower clusters (FlCl) after June drop; thinning effect compared to control (%); crop load before harvest (% of optimum); incidence of fruit russeting (% incidence); fruit weight (g). Interaction treatment * cultivar is significant; in all cases differences between control and 15 kg/ha were significant, except for Maigold where this is the case with 20 kg/ha.

In 2009 also different alternative methods were tested on cv. Topaz and Otava. Natural fruit fall, however, was high this year due to a relatively cold climate causing sub-optimal conditions for assimilation for the trees during Mai. For this reason, even in the untreated control variant and with both cultivars, crop load at harvest was only 10 % too high in the untreated control plots. At the fruit counting date before June drop, the treatments 2 x 20 kg/ha Armicarb and rope device plus 3 x 7% vinasse showed a significant but low thinning effect of 12.8 and 18.9 %. 3 x 2.5% lime sulphur with 30.4 % thinning effect was significantly more effective than the latter treatments. As in 2008, net shadowing reduced fruit set too radically by 67.1 %. The interaction treatment * cultivar was not significant. The results of this trial are not shown in detail.

Experiments 2010

In 2010 Armicarb concentration trials were performed with 15 kg/ha on cv. Golden Del., Braeburn, Pinova, Gravensteiner, Topaz, Otava, Ariane (scab resistant), and with 20 kg/ha on Maigold. The good thinning effect of Armicarb at these concentrations could be confirmed, though, as a consequence of the varying intensity of the natural June drop in the control plots, the thinning effect (expressed as % difference to the untreated control) could vary considerably between the fruit counting before and after June drop (Tab. 3). Nevertheless, with all cultivars, either before or after June drop significant and for practical fruit growing relevant thinning effects in the magnitude of 13 % (Otava) to 52 % (Gravensteiner) could be achieved.

Table 3: Thinning effect of Armicarb (2 x 15 kg/ha) in the 2010 trials with different cultivars as assessed before and after June drop. Asterisks indicate statistically significant effects (post ANOVA Tukey HSD tests at $p < 0.05$).

Cultivar	**Thinning effect before June drop (%)**	**Thinning effect after June drop (%)**
Braeburn	22.4*	21.8*
Golden	30.0*	44.5*
Gravensteiner	29.0*	52.3*
Otava	11.9*	13.2*
Pinova	24.6*	15.6
Topaz	9.8	37.1*
Maigold (20 kg/ha)	45.8*	16.7

Figure 4 shows that beside the total thinning effect, with all cultivars, the 15 kg/ha Armicarb treatment also reduced the proportion of flower clusters with 3 or more and 2 fruitlets in favour of clusters with 1 or 2 fruitlets, respectively; from the perspective of the fruit grower a most desirable pattern.

The 2010 trials to compare different alternative methods carried out on cv. Elstar and Topaz included applications of lime sulphur, Armicarb standard (15 kg/ha), Armicarb 15 kg/ha in combination with a rope device application at stage E (59) and “Black Oil”. In 2010 the weather conditions right after blooming period were unusually cold and rainy during 24 days. The conditions for assimilation and fruit set were therefore sub-obtimal. For these reasons, the results of these method comparison trials are to some extent difficult to interpret and not shown in detail: The counting before June drop revealed a generally very high fruit set with 230 to 245 fruits per 100 flower clusters over all treatments including the by 2/3 hand thinned trees (as a compensation reaction, these latter trees kept most of the remaining fruits and thus had a high number of > 2 and > 3 fruits per fruit cluster). At this date, only the lime sulphur treatment (2 x 2.5 vol.%) revealed a moderate thinning effect of 22.3%. After June drop, however, fruit set dropped drastically to 85-111 fruits/100 FlCl in all treatments (including untreated control) with the exception of the lime sulphur treatment which decreased to 58 fruits/100 FlCl, and therefore was even over-thinned. Consequently at harvest 2010, the remaining treatments appeared with a near optimal crop load, again without significant treatment differences.

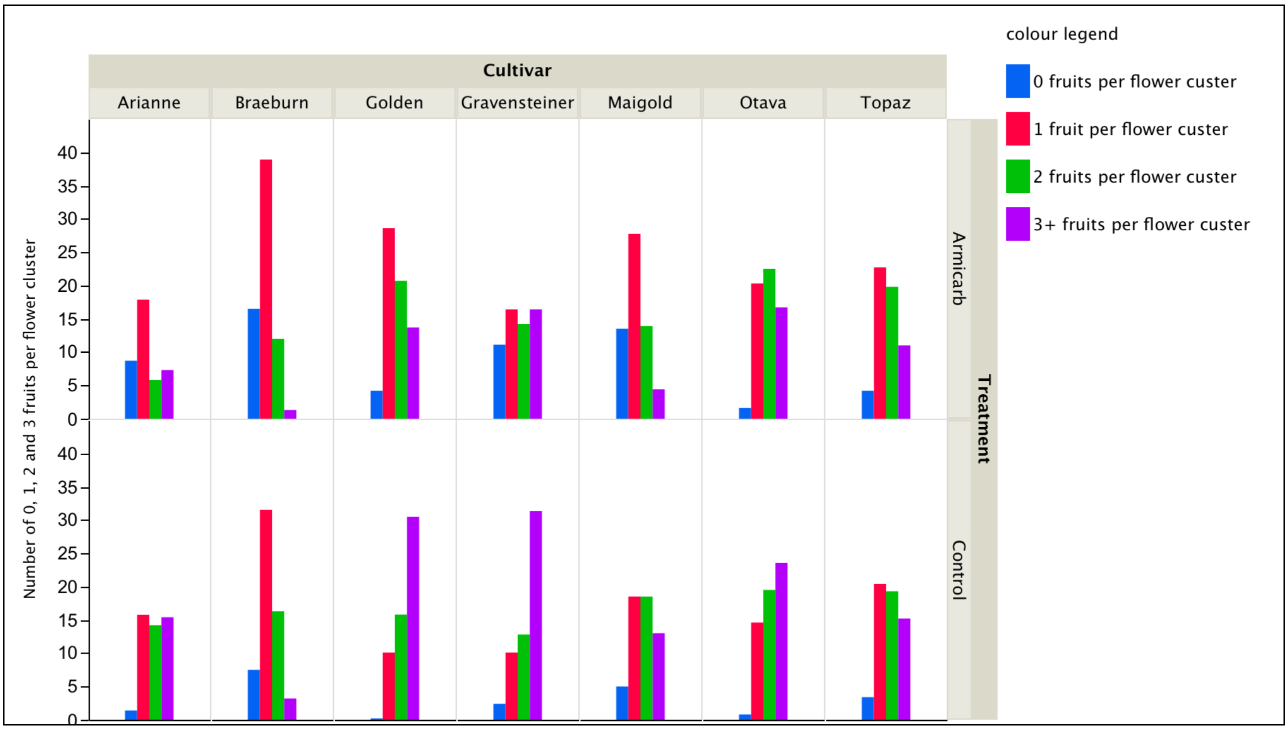


Figure 4: Mean numbers of fruits per flower cluster per cultivar and treatment, counted before June drop 2010 in the treatment with 2 x 15 kg/ha Armicarb; Maigold with 20kg Armicarb.

In the trials of 2010 no variant showed signs of treatment-induced russeting. For this reason, the assessments of russeting incidence and severity were not carried out that year.

Discussion

Armicarb is a well known product against scab and sooty blotch on apple (Tamm *et al.,* 2006). Since presently no active compound is allowed for fruit thinning in organic apple production in Switzerland, Armicarb is an interesting candidate for organic apple thinning. Pfeiffer (2008) studied the thinning effect of Armicarb where it was applied as a fungicide at a rate of 5 kg/ha: Very much in line with our study, there was too little thinning effect of Armicarb at that dosage. To our knowledge, so far there are no other longer-term and multi-cultivar studies published (including return to bloom data) where Armicarb was tested at higher dosages as a thinning agent. In our experiments, we could show that Armicarb has a high thinning potential and that its effect is cultivar and concentration dependent. The concentration experiments over 3 years showed that Armicarb has a significant thinning effect with a concentration of 15 kg/ha for 10 of the cultivars tested and with 20 kg/ha for cv. Maigold. Interestingly, a further concentration increase did not induce a stronger thinning effect but increased the incidence of russeting.

Our results are in line with previous findings (Weibel *et al.,* 2008) confirming that the rope device combined with vinasse is a fairly efficient thinning method with a comparable efficacy as hand thinning and lime sulphur. Furthermore, with a vinasse concentration of 5-7.5% and 2-3 applications during blooming phase, we did not observed phytotoxic effects. To avoid damages on wood, spurs and leaves (Baab & Lafer, 2005) it is important to use the rope device as soft as possible by driving at high tractor speed (9-11 km/h) and at moderate rev./min. of the rope spindle (Damerow 2007 & Weibel *et al.,* 2003).

In our experiment, hand thinning by 2/3 was consequently included as ‘positive’ control treatment (Dennis, 2000 and 2002). However, beside unaffordable costs for labour these trees tend to compensate the removed flowers by keeping a high proportion of fruits on the remaining flower clusters and show a high proportion of flower clusters with 2 and 3 and more fruits (Kloss & Weibel, 2009).

Goemar® GA14, vinegar (5 g/L acetic acid) and "Black Oil" did not show significant thinning effects in these trials and are therefore not profoundly discussed.

Our results on shadowing are in line with previous studies which showed that tree shading can be an efficient thinning method (Stadler *et al.,* 2005, Kockerols *et al.,* 2008). According to Stadler *et al.* (2005) we mounted the nets 22-23 days after full bloom and we based our shading duration on the recommendation of A. Widmer (ACW, Wädenswil) who suggested 5-6 days for Elstar and 4 days for Idared but got over-thinning with both cultivars in both years. We suppose that in our experiment, this shading duration was too long under the circumstances given with low natural radiation and an additional hail net.

Conclusions

From our experiments, and for the cultivars and conditions tested, we draw the following conclusions for the practical application for organic thinning measures during bloom:

1. With the majority of cultivars, 2 applications during bloom of 15 kg/ha potassium-bi-carbonate (Armicarb) gave a satisfying result. Only with cultivar Maigold 2 x 20 kg gave a better result.
2. When applying Armicarb on not yet tested cultivars, 15 kg/ha is a recommendable starting concentration for tests. The optimum, however, can range between 12-20 kg/ha.
3. The application of Armicarb should take place at warm, sunny days without rain in the following 12 h and at a time with a maximum of still un-pollinated flowers wide open. Thus, depending on the duration and intensity of the blooming phase, 2-3 applications are necessary.
4. With some cultivars like Elstar, Gala, Golden Delicious and climatic conditions that favour russeting, the use of Armicarb for thinning can increase the incidence and severity of fruit russeting. In particular it has to be avoided that it starts drizzling shortly after the application of Armicarb.
5. When Armicarb is also intensively used for scab and sooty blotch control, the potassium levels in the fruit flesh can increase to a magnitude where inner fruit quality can be negatively affected (K:Ca-ratio > 35) (Weibel 2010, unpublished data).
6. We achieved good thinning results also with 2-3 applications of lime sulphur at 2.5%, and vinasse at 7% concentration at the same conditions as mentioned above for Armicarb. Vinasse is particularly efficient with e.g. cultivar Topaz.
7. The efficacy of vinasse can or even should be improved with a soft application of the rope thinning device at stage red tips (E 59), followed by two or three applications of the desiccant agent during flowering period.
8. The thinning effect of the rope device is due to a physiological shock followed by a lack of assimilates for the development of the fruitlets (Greene 2002, Wünsche and Ferguson 2005). Thus, this method should be applied at colder, cloudy days to increase the effect of the photosynthesis decreasing effect. The Rope device should not be used during full bloom because then too many primary leaves will be destroyed and the physiological shock will cause long-lasting negative effects (e.g. compensatory shoot growth in summer etc.).

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