The post infection use of Lime sulphur to control apple scab. Experiences in the Netherlands 1999–2002

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Abstract

Until yet the fungicides in organic fruit growing (sulphur, lime sulphur, copper, claypowders) are used as protectants applied before the rain, or as stop-spray or during infection development. Post infection use of lime sulphur could reduce the number of spray rounds, allowing for the use of less pesticide, and reducing the adverse effect on beneficial insects and mites.
In the 30's of the last century post-infection effects of lime sulphur where found in lab and field trials. Effective control was achieved by applications 30 to even 72 hours after the start of rain. Field trials in the Netherlands in 1999, 2000 and 2001confermed that post infection applications of lime sulphur are effective under field conditions till at least 20 hours after the start of the infection.
Evaluation of the practical experiences with the use of lime sulphur as post infection spary 2000 and 2001 however learned that a dose of at least 0,15 % should be used, and the product should be applied with a high water volume, or on wet leaves to allow for a effective contact between the pentasulphides and the fungus.
In 2000 one application of lime sulphur two weeks after blossom lead to severe russeting of the fruit skin on the variety Jonagold.

Introduction

The fungicidal and insecticidal properties of lime sulphur where revealed in the 19th century. At the beginning of the 20 the century the use of limes sulphur to control apple scab spread to all major fruit growing regions in the world. It was welcomed as alternative to the use of Bordeaux mixture as Bordeaux has strong phytotoxic effects. In the first halve of the 20th century lime sulphur was worldwide de one of the most important fungicides for the control of apple scab. After the second world war its use declined as equal effective and less phytotoxic organic fungicides as thiram ferbam and captan came available.
At this moment lime sulphur still has a registration as fungicide in many countries but in the western world the use is reduced to 'home and garden use and as environmental save fungicide in organic agriculture. Recent years several trials where made to optimise the use of lime sulphur to control apple scab in organic fruit growing. (Kelderer 1997, Kelderer 2000, Zimmer 2000)
In the 30's of the last century post-infection effects of lime sulphur where recognized in field trials, but the treatments where found to be most effective the sooner they where applied after the beginning of rain. (Gloyer 1933) Hamilton found in his trials on potted plants infected in a moist chamber good control with applications up till 30 to 72 hour after inoculation. (Hamilton 1931) In his field trials he obtained good control with lime sulphur when applied 43 to 47 hours after start of rain. (Hamilton 1932).
Mills stated that 'At most favourable temperatures thorough spraying with lime sulphur will prevent scab infection when applied within 50 hour after the beginning of the rain, and at lower temperatures for a considerably longer period (Mills 1944).

Until yet the fungicides in organic fruit growing (sulphur, lime sulphur, copper, claypowders) are used as protestants applied before the rain, or as stop-spray or during infection development. Post infection use of lime sulphur could reduce the number of spray rounds, allowing for the use of less pesticide, and reducing the adverse effect on beneficial insects and mites. After march 2000 copper was not longer approved as fungicide in the Netherlands. For the Dutch organic growers it was of the highest importance to evaluate the properties of lime sulphur to control apple scab.

Materials and Methods

Small plot field trials

In 1999, 2000 and 2001 the effectiveness of post infection applications of lime sulphur was evaluated in field trials. The trials where made on Jonagold, the main variety in the Netherlands and regarded as highly susceptible to apple scab. The trial orchard in Zoelmond was left unsprayed in 1998, yielding a high ascosporic inoculum in 1999. Trails where run each year during the primary infection season. The trees where left unsprayed for the rest of the year to allow for the build up primary inoculum for next years trials. No other pesticides where used.
In each year untreated objects where compared to three different strategies of lime sulphur application. The strategies differed in the moment of application relative to the moment of infection. In 2000 the treatments in the strategies to be compared where made almost exactly 10, 20 or 30 hour after infection. In 1999 and 2001 the timing was more variable. (table 1) Trials where run in a random block design with three replications.
Weather information was collected with a onsite Campbell data logger. Apple scab infections where calculated by the scab simulation program RIMpro. (Trapman 1994, 2000). The moment of infection was regarded as the moment that according to the simulation the first ascospores penetrated the leaves. (RIM-value >10). Infection periods with a low infection risk (RIM-value The lime sulphur used in all trials was a product of Polisenio, 48022 Lugo, Italy, (30-32 Bé at 20 C ,containing 17 % of CaS_5)
Applications where made with a hand held sprayer. Trees where sprayed until 'run off ' with a 1.5 tot 2.0 % v/v lime sulphur dilution.
Observations on disease incidence where made by counting the number of scab infected leaves per 100 organs. (early season rosettes, later in season rosette + shoot leaves)

Table 1: Lime sulphur applications in the trials in Zoelmond 1999-2001. Application time in hours before (-) or after (+) the beginning of the Apple scab infection.

	Infection 1	Infection 2	Infection 3	Infection 4	Infection 5
1999	3 April	12 April	22 April	6 May	11 May
Preventive-stop spray	- 5	- 19	- 14	+ 6	+ 8
8-26 hour post infection	+ 8	+ 26	+ 9	+ 12	untreated
20-56 hour post infection	+ 20	+ 56	+ 34	+ 31	untreated
2000	14 April	22 April	30 April	17 May	
10 hour post infection	+12	- 48	+ 11	+ 11	
20 hour post infection	+ 21	- 48	+ 21	+ 21	
30 hour post infection	+ 31	- 48	+ 31	+ 31	
2001	16 April	25 April	3 May	15 May	
Preventive-stop spray	- 3	-1	- 5	- 6	
10-20 hour post infection	+ 21	+ 20	+ 18	+ 10	
20-30 hour post infection	+ 31	+ 32	+ 26	+ 20	

Practical field trial

In a organic orchard near Eindhoven in 2000 and 2001 two scab management strategies where compared:

1. Protective applications with wettable sulphur. (Thiovit, Syngenta Crop Protection, 80% sulphur). Applications shortly before the start of rain, or on wet leaves before the infection occurred.
2. Post infection applications of lime sulphur. (Polisenio) . Applications within 20 hours after infection had started.

The treatments as they where made in both years are in table 2 and 3
The trial orchard consisted of the apple varieties Elstar and Jonagold, the two main apple varieties in the Netherlands. The 1 hectare orchard was cross subdivided in 4 blocks. The strategies where applied as two replications in the two di-

agonal opposite segments. There was no field left untreated. Autumn 1999 most of the shoots of Jonagold where infected by apple scab so a abundance of primary inoculum could be expected spring 2000.
Weather information was gathered by an on site METY weather station. (Mety, Dordrecht, Netherlands). Scab infections where calculated with the simulation program RIMpro and interpreted as explained above.
Fungicide applications where made with a tractor pulled sprayer using 300 litre of spraying solution per hectare.
Trials where conducted during primary infection season. To prevent secondary infections form the second halve of May onward the orchard was treated regularly with wettable sulphur (3- 6 kg./ha).
Observations on disease incidence where made by counting the number of scab infected leaves per 100 organs at regular interval during the season.

Applications in commercial orchards

After march 2000 copper is not longer approved as fungicide in the Netherlands. In 2000 and 2001 organic apple growers in The Netherlands used lime sulphur as alternative to copper fungicides for the control of apple scab, mainly during the period of ascosporic infections.
Disease development in a number of orchards was monitored on both fruits ad leaves and the spray plans where compared to draw conclusions on the results of the scab management.

Table 2: Fungicide applications in the trial at 'De Wielewaal, Eindhoven, 2000 (Kg./ litre product per hectare)

Date	Condition of the trees during application	Wettable sulphur Protective	Lime sulphur Post infection
14 March	Dry	4 kg	
24 March	Wet	4 kg	
25 March	Wet		12 litre
1 April	Dry	4 kg	
13 April	Dry	4 kg	
14 April	Wet		12 litre
21 April	Dry	5 kg	
23 April	Wet		12 litre
29 April	Wet	3 kg	10 litre
3 May	Dry	3 kg	
8 May	Dry		10 litre
16 May	Wet	5 kg	
17 May	Dry		10 litre
23 May	Dry	3 kg	
29 May		4 kg	
31 May			12 litre
Number of treatments		10	7

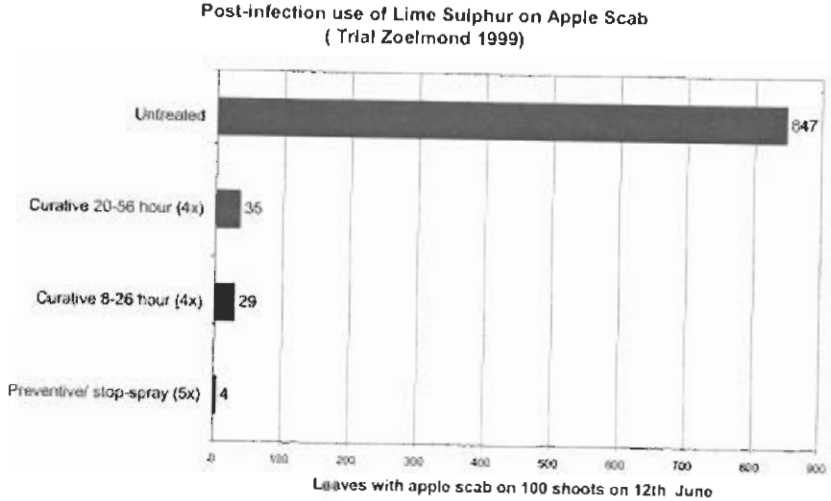
Table3: Fungicide applications in the trial at 'De Wielewaal', Eindhoven, 2001 (Kg./ litre product per hectare)

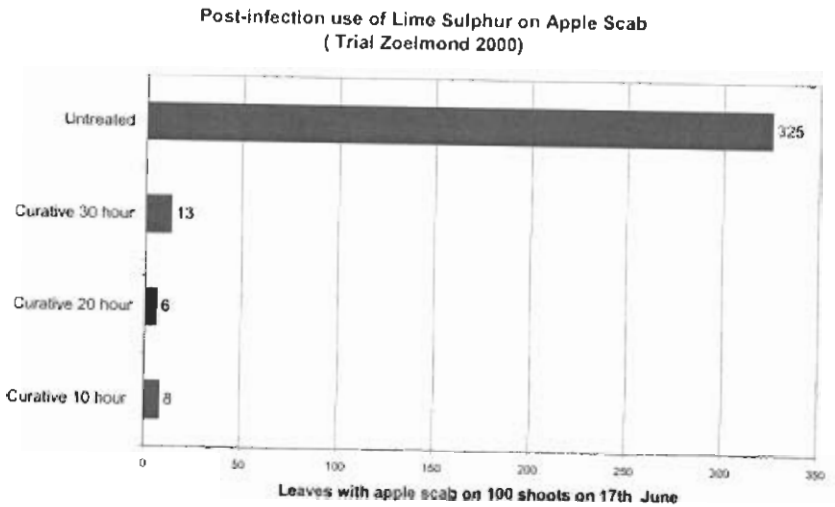
Date	Condition of the trees during application	Wettable sulphur Protective	Lime sulphur Post infection
3 April	Wet	4 kg	
6 April	Wet	4 kg	15 litre
10 April	Wet	5 kg	
11 April	Wet		15 litre
17 April	Wet		15 liter Lime sulphur
24 April	Wet	5 kg.	
27 April	Wet		15 liter Lime sulphur
3 May	Wet	5 kg.	
4 May	Wet		10 litre
16 May	Wet	6 kg	
19 May	Dry		Sulphur 6 kg + Goemar 2 l.
24 May	Wet		Sulphur 6 kg + Goemar 2 l.
Number of treatments		11	7

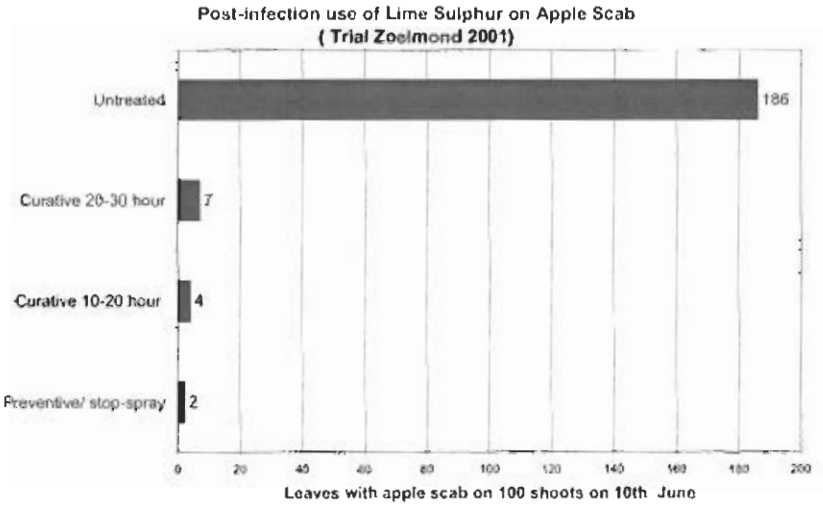
Trial Results

Small plot field trials in Zoelmond

The results of the trials in Zoelmond are presented in graphs 1 to 3. Details on the results of the trials in 1999 and 2000 have been published earlier. (Trapman and Drechsler-Elias 2000)
In all three years the post infection applications where 95–99 % effective to control apple scab. There where no significant differences between the treatments made directly after or 30 hours after infection. The higher disease incidence in the curative objects in the 1999 trial was due to a secondary infection that was treated in the protective plots but left unprotected in the post infection plots. (Table 1) In the observations made on 25 May there was no significant difference between the two post infection treatments and the protective treated plots.







Practical field trials in Eindhoven

In 2001 during two infection periods (on 17 and 27 April) is was not possible to get the protective sulphur treatments on in time. On these occasions the whole orchard was treated with Lime sulphur within 20 hours after the start of infection. The results of the trials measured as the disease level after all primary infections on the leaves had become visible in June, and the percentage scab infected fruits at harvest, are presented in table 4. In both years the post infection treatments with lime sulphur where as effective as the protective scheme with sulphur. In both years several spray rounds in spring where saved y the post infection use of lime sulphur. With the post infection strategy 3 and 4 sprays could be saved during primary infection season.

Table 4: Results of the trial at 'De Wielewaal, Eindhoven, 2000-2001 (average figures of the two replications)

	Date	Elstar		Jonagold	
		Wettable sulphur protective	Lime ulphur Post infection	Wettable sulphur protective	Lime sulphur Post infection
2000					
Leaves with apple scab at 100 shoots	22 June.	6	0.5	20.5	20
Scab infected fruits	Harvest	0.4 %	0 %	0.2 %	0 %
2001					
Leaves with apple scab at 100 shoots	28 June.	0	0.5	5.5	8
Scab infected fruits	Harvest	0 %	0 %	0 %	0 %

Discussion

Te results from these trials confirm the information from e.g Hamilton and Mills that lime sulphur can be used to control apple scab infections post infection. Based on these experiences a practical strategy based on applications with lime sulphur within 20 to 30 hours after the start of infection should be effective. In other trials in Norway and The Netherlands in which the post infection application of lime sulphur was delayed until 36 to 40 hour after start of infection the post infection applications where slightly less effective then the protective applied lime sulphur in the same trials. (Stensvand 2000, Heine 2000)
Recent, until jet unpublished, lab and semi lab studies (Schwabe 2000, Marchal 2000, Palm 2001) show that the effectiveness of lime sulphur declines rapidly after about 200 hour degrees after infection.
There is however an important difference between trials made under artificial conditions and field trials. Under lab conditions plants are artificially inoculated: all spores are brought on the plant surface at the same time. Infections are made at lab or green house temperature, mostly between 15 and 20 C. In the field temperatures are fluctuation, and on average much lower. The ascospores are being discharged over a longer time period, leafwetness periods may be intermitted, and the infection process takes more time. The whole process leads to a much wider dispersion in the developmental stages of a field population of germination and infecting spores. Even in the case a treatment is made at 30 hours after beginning of infection, a lager part of the population is in a less progressed stage. Field trials are likely to show effectiveness longer after beginning infection than lab studies.

Despite these good results in trial situations, the results of the post infection application of lime sulphur in practise was not always as effective, and several drawbacks of these applications have to be considered.

Effectiveness

Many practical growers applied in 2000 and 2001at least twice as many applications as in the Zoelmond trials with absolutely unsatisfying results. Both in 2000 and in 2001 several organic farms ended up with more than 50 % scabbed fruits. From the comparison of the spray notes, and discussions with the growers several possible explanations where revealed.

Active dose

In the trials a 1.5 tot 2.0 % v/v dilution of Lime sulphur was used. Depending on the water volume needed to wet the orchard, and a density of 1.26 this is comparable to a dose 19 to 38 kilogram of lime sulphur /ha. The growers mostly used 10 to 15 kilogram per hectare. (extremes 6 and 25 litre). Most growers are using an alternate row spraying system to apply their spays. They spray the total of their farm every second row, and that turn back to treat the other rows. Depending on weather conditions and orchard size there can be several up to 24 hours between the treatment of one and the other side of the tree.

Dose is critical to get good results. Hamilton considered 1/60 (1,7% v/v) as as effective as the normal rate of 1/40 (= 2,5 % v/v). A 1/80 dilution (=1,25% v/v) was in his few only effective in periods with low infection risk.(Hamilton 1931) 2 % v/v is the normal dose often mentioned in the literature of the first halve of the 19th century. 1,5-2,0 % the rate currently advised in Northern Italy for pre blossom sprays. (Kelderer 2001) Zimmer also found 20 litre/ha. to be more effective then 10 litre/ha. (Zimmer 2000) This means that the dose used by the Dutch organic growers in 2000 and 2001 was relatively low.
Calciumpentasulphide, the main active ingredient regarding the post infection activity of lime sulphur is instable when diluted in water and brought under atmospheric conditions.. Circumstantial evidence (Doran 1922, Hartsuiker 1941, Tweedy 1981) suggest that within several hours the pentasulphides are reduced to elemental sulphur and other sulphur metabolites that only have a protective effect on apple scab infections. This means that by applying two times half rate as is done by alternate row spraying at least a part of the product may have been metabolised the moment that the second halve of the rate was applied. Leading in time and place to a much lower active dose of pentasulphides on the treated apple leaves than necessary for good post infection control.

Spray volume

In our trials sprays where applied until run off, and/or the sprays where applied on wet leaves. In the fungicide trials mentioned in literature the products where also applied until run off. Dutch apple growers are used to apply their fungicides as concentrated sprays with 125 to 300 litre of water per hectare. They rarely spray on wet leaves as trials revealed that technically the distribution of pesticides is much better when applied with lower rates of water and on dry leaves.
In practice worst results where obtained by the growers using high travel speed, low water volumes and alternate row spraying with relatively large time interval between both sides of the trees. Best results where obtained by growers using higher water volumes, or treatments on wet leaves during infection development, smaller orchards that makes shorter time intervals between treatment of both sides of the trees.
Literature is not consistent in the role of the high pH of the spraying liquid in the effectiveness of lime sulphur on apple scab, but if the caustic effect plays a role, it can only be the during wet phase directly after spraying. The pentasulphides able to penetrate the fungus and kill it can only do so in water phase and in direct contact with the fungus. There is no systemic transport of the fungicides in the leaves as with modern post infection fungicides. Low volume sprays on dry leaves that cover only 4-10 % of the leave surface are therewith likely to have worse results.
When lime sulphur is not used as post infection fungicide but as protectant, not the pentasulphides but the elemental sulphur formed after the reduction of the polysulphides on the leave acts as active ingredient. In that case alternate row spraying and water volume does not influence the effectiveness of the fungicidal activity.

Phytotoxic effects

After almost every application in the small plot trials in Zoelmond damage to the expanding leaves was visible, ranging from reduced leaf growth, asymmetric development of the leaves, a yellowish decolouration of leaves, to burning of the tips and sides of the leaves. To a lesser extend these effects where also visible in the commercial orchards where lime sulphur was applied. In the literature phytotoxic symptoms are related to treatments preceding a frost period, treatments at a temperature above 32 C, and combinations with oils. Also is mentioned that trees in weak condition suffer more that healthy trees with a balanced growth. The latter could be confirmed by our observations.
In 2000 both in our trials and on commercial farms treatments with lime sulphur two weeks after blossom (second halve of May) caused severe russeting of the fruit skin. This russeting occurred on the variety Jonagold on all farms in the Netherlands and Belgium where lime sulphur was applied in that period. On average 26,4 % of the Jonagold yield (average of 23 orchards) was not marketable as table fruit due to severe russeting cased by one lime sulphur spary.

No cases of russeting on Elstar, Boskoop or Cox's could be correlated to the use of lime sulphur. The cause of these russeting on Jonagold could not be revealed. No combinations with oil or other spraying materials where made. No relation to the weather conditions during the applications could be found. The weather conditions during the casual applications and the resulting russeting in the Zoelmond trials are given in table 5.
The only remarkable fact was that during the first two weeks after blossom there had been unusual fair weather with low RH and max temperatures of 30. The day before the casual sprays the weather changed to cold an rainy with an max temperature of 15 degrees. This sudden change in climate could have made the young fruit skin more susceptible for spraying materials.
Applications of lime sulphur on Jonagold in other regions (Northern Germany, Southern Germany) in the same period in 2000 did not result in russeting. In 1999 and 2000 no russeting occurred after the use of lime sulphur shortly after blossom .
In trials where lime sulphur was tested as fruit thinning agent throughout Europe in 2000 and in other years high rates of lime sulphur where applied during blossom. Extreme russeting caused by these treatments was never reported.

Table 5: Weather conditions during the lime sulphur application and resulting fruit skin russeting in the Zoelmond trial in 2000.
(average of 3 replications)

Plot	Object	Weather conditions		Severely russeted fruits
0	Untreated			3 %
1	17-5 day 15:30	Leaves dry, wind, Quickly drying	17 C, 60 % RH	28 %
2	18-5 night 01:30	Leaves dry, some wind, Quickly drying	11 C, 72 % RH	31 %
3	18-5 day 12:00	Leaves wet, immediately after rain, trees dry at 13:00 hour.	10 C. 90 % RH	44 %

Conclusion

Lime sulphur can be used for post infection control of apple scab until at least 20 hour after the infection has started. At least 1,5 % lime sulphur should be used. The leaves should be wetted thoroughly by application of high volume sprays, or application during the time the leaves are still wet.
The risk of russeting of the fruitskin on Jonagold by post blossom application can not be excluded.

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