A simulation program for the timing of fungicides to control Sooty Blotch in organic apple growing.

First results in 2003

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Abstract

A simulation program for infections by Sooty Blotch was developed based on literature data and expert judgements. The value of the model as tool for timing fungicide sprays to control Sooty Blotch was tested in 2003 in two randomized plot trials, and four “on farm” trials where the treatments where made by the growers. Disease pressure was relative low due to the warm and dry summer of 2003. Two to five post infection treatments with lime sulfur or coconut soap aimed at severe infection periods as indicated by the model provides 72 to 100 % control.

Introduction

Sooty blotch is an important disease in organic apple orchards where no summer fungicides are applied. In orchards with apple scab-resistant cultivars (Vf resistance) that are managed with minimum fungicide input, losses until 100% due to diseased fruit are regularly reported. Reports come form all over Europe: form the Alps until even in Denmark (Lindhard, 2003; Tamm, 1997; Fuchs et al., 2002).

The occurrence of SB greatly reduces the practical benefits of the culture of scab resistant apple varieties as the fruitgrowers tend to treat these varieties during summer against SB almost as frequently as they need to spray their standard varieties to prevent apple scab infections.

Coconut soap and lime sulphur are fungicides allowed to be used in organic fruit growing that have been proven effective against SB infections. (Kienzle ea 1995, Zuber 1997, Tamm 1997, Fuchs ea 2001,2002).Until now there exist no warning system to schedule the application of these fungicides in organic orchards. Existing empiric SB-models and control strategies (Brown & Sutton 1995, Hartman 1995, 1997, 1998, Rosenberger 1997, Ellis ea 1998, Leahy 2002) estimate the moment that first SB symptoms will appear in the orchard, and facilitate therewith the application of eradicant fungicides. These models do not provide information on the moments and severity of the preceding SB-infections.

Description of the model

Spring 2003 a first version of an infection model for SB was constructed based on literature data and judgements of experts. The model was programmed as a dynamic simulation program using boxcar trains to mimic delays and dispersion. (Rabbinge 1989) Visual Basic 6 was used as programming language. The SB-model was added as separate module to the RIMpro apple scab program (Trapman 1994) so that file management, input-output routines and user interface of this existing program could be used. A flow diagram of the program is presented in figure 1

Biofix

The moment from what the fruits are susceptible for infections by SB serves as starting point for the calculations. Fruit infections by SB seem to be possible form

Bio Fruit Advies, Netherlands

about 10 to 21 days after bloom. (Brown & Sutton 1993) or within 1 month after bloom (Hickney ea 1958). In Germany Barbara Kopff determined first infections of Sooty Blotch in Lake Constance area. She concluded that in 2001, 2002 and 2003 first infections occurred not earlier than in June.(Kopff 2003) In the 2003 version of the SB-program we set the Biofix rather conservative at 10 days after full bloom. Infection calculations are made from that day onwards.

Spore release from inoculum
In organic orchards we expect spores formed by the mycelium on the bark and twigs of the apple tree to be the primary source of SB inoculum. Spores are mainly splash distributed. This means that a minimum rain intensity is needed to get distribution of spores onto fruits and other parts of the tree. The minimum rain intensity to get this splash distribution is not known but was set at 0.5 mm of rain in 30 minutes which is regarded to be a save setting.
Until now, rain is only used as trigger in the SB-model. Ongoing rain has no quantitative influence on severity of the infection. As soon as the minimum conditions are met a fictive number of 1000 spores are ‘released ‘in the infection process.

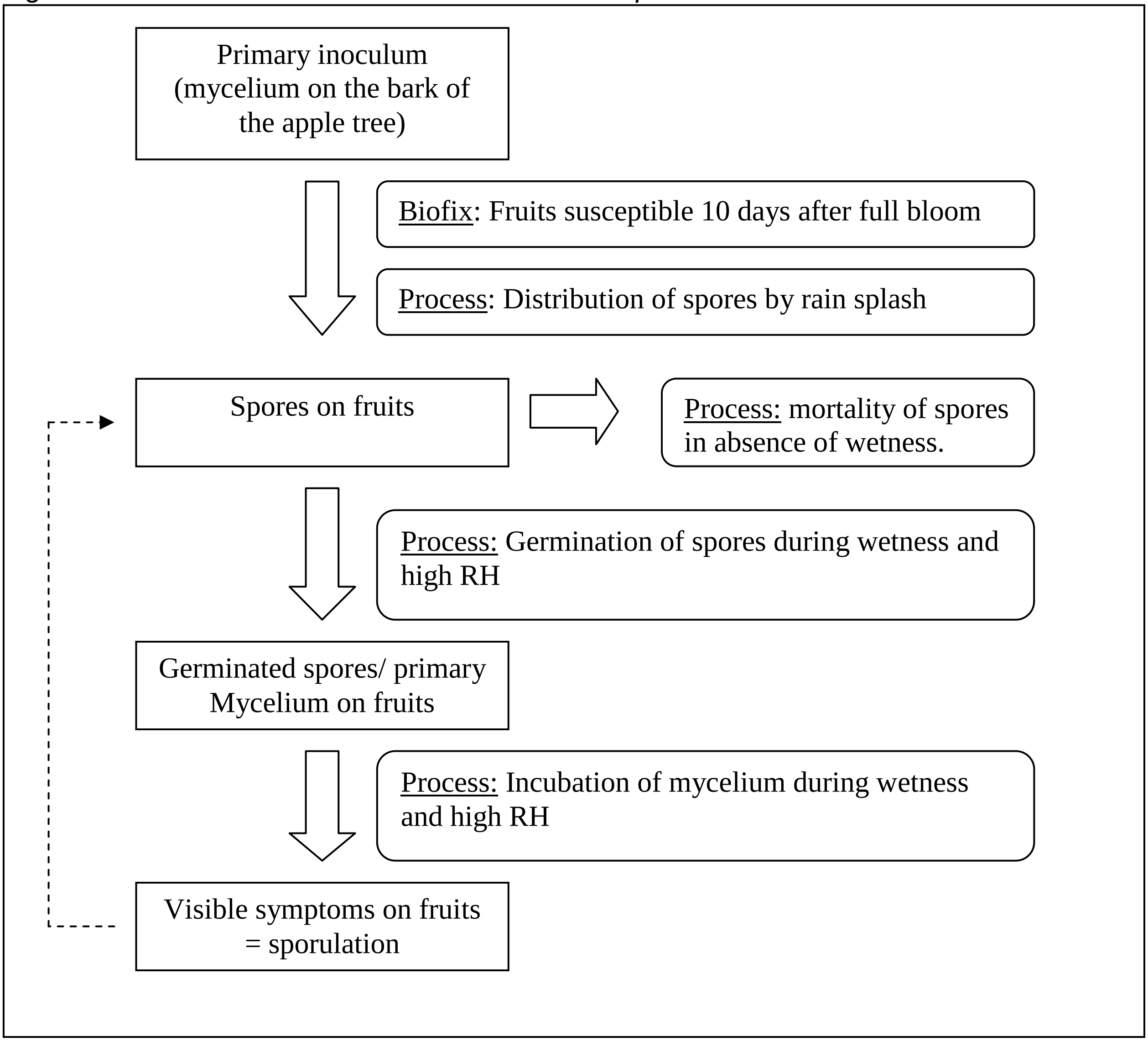
Development rate for the infection process
The infection process runs as long as the leaf wetness sensors read “wet” or the RH is over 97 %. Infections no not develop below 10 ℃ or over 30 ℃. The optimal growth range of the fungi is 16-24 ℃ Temperature d epended developmental rate for the infection process was derived form the data published by Johnson & Sutton (Johnson & Sutton 2002) for *Peltaster frucicola.* (after some interpretation and transformation of the published data).

Mortality
Spores that have not finished the infection process are susceptible to dry intervals. Johnson & Sutton (Johnson & Sutton 2002) provide some data on mortality of spores during dry intervals. Derived from this data the current SB-model uses 8 hours as average survival time for germinating spores with a relative dispersion of 0.25.

Incubation
Published data on the incubation period for SB infections are contradictive. The incubation time seems to correlate to cumulative wetness time. Reported data range from 50-100 hours of high RH (Sharp 1985), 209 to 310 cumulative hours of wetting longer that 4 hours (Brown & Sutton 1995), 236-586 hours of wetting(Hall ea 1997), 225 to 489 hours of wetting (Ellis ed 1998), 251, 224, 185 and 221 hours of wetting (Hartman, 1995,1996,1997,1998) The values found seem to be dependent on the measurement equipment used, whether or not wetness periods shorter than 4 hours are included, the trial setup and on the SB inoculum. In the SB-model the default setting for the incubation time of 275 wetness hours with a standard deviation of 25 wetness hours. This causes first symptoms to occur roughly at 225 accumulated hours of wetness after infection and full expression after 325 hours of wetness.

Not (yet) in this model
Not included in the 2003 version of the model are inoculum level, the quantitative influence of rain, and the secondary infection cycles on fruits which are pictured as a dashed feedback line in the flowchart.

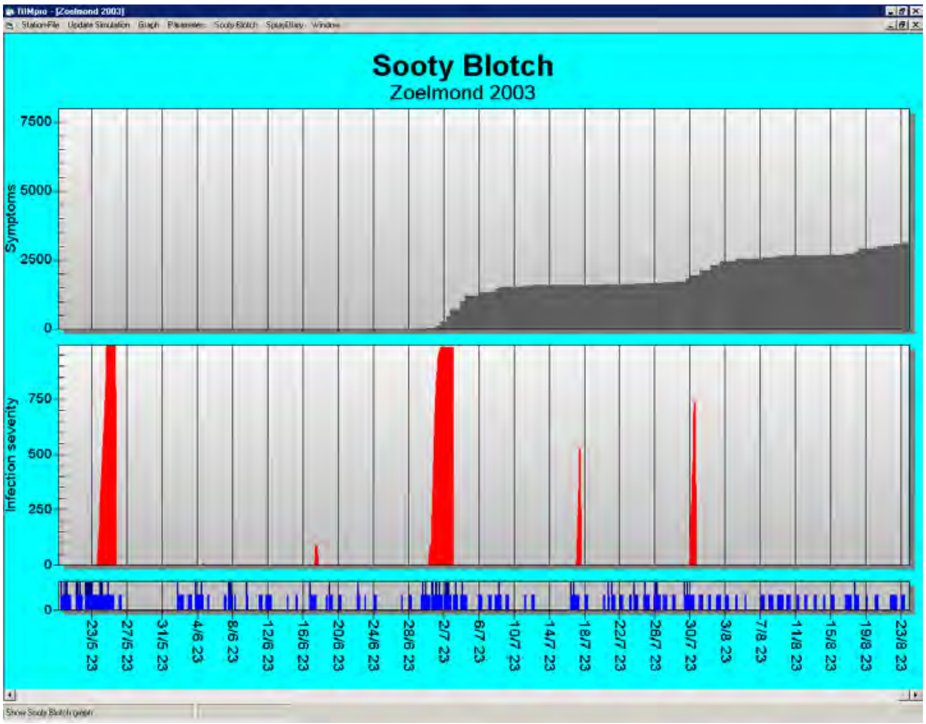
Figure 1: Flow chard of the SB model within RIMpro 2003



Output

Figure 2 gives an example of the program output. In the bar below the lower graph the measured leaf wetness readings and rain events are plotted. In the lower graph in red the infection severity as calculated by the SB-model is presented. In the upper graph the expected accumulation of visible symptoms on fruits is represented by the grey area. For instance symptoms of the first severe SB-infection 24-25th of May should become visible just at the time that the second severe infection occurs at the beginning of July.

Figure 2: Example of the output of the SB-model within RIMpro 2003



Material and methods

The value of the model as tool for timing fungicide sprays to control SB was tested in 2003 in two randomized plot trials, and four “on farm” trials where the treatments where made by the growers. The weather data to drive the model where collected with weather stations standing in or in the immediate surrounding of the the trial orchards. The SB-program was run on location. Several technical bugs have been found in the program during the first month of the trials that have been corrected. Fungicide treatments where made within 20 hours after the onset of a severe SB-infection according to the model. With a maximum infection value in the model of 1000, applications were made if the infection level was over 500. Treatments where made with high water volume (at least 500 litre /ha) and whenever possible applications were made on wet leaves. In different trials coconut soap (“Cocana”, Biofa, Münsingen, Germany)), lime sulfur (“Polisolfuro di calico”, Polisenio, Lugo, Italy) and a mixture of coconut soap and copper oxychloride were uses as fungicides to control SB.

Orchard Zoelmond

Variety Topaz, 4 replications, 7 trees per plot. In 2002 100 % of the fruits in this orchard were severely infected by SB. Weather data where collected with a Metos Compact weather station (Pessl Instruments, Weiz, Austria) standing within 20 meters of the experimental plots. Lime sulphur was used as fungicide at 1.0 %.(v/v) Applications where applied with a Stihl SR 400 mist blower. Infection and application dates are given in Table 1. The total accumulated number of wetness hours between 10 days after petal fall and harvest is calculated as the number of hours with RH > 97%.

Table 1:
Infections according to the SB-model and application dates for the Zoelmond trial

Date	According to the SB-Model		Applications of Lime sulphur 1.0%
	Infection	First visible symptoms	
24-25 May	Severe	30 June - 4 July	
1-2 July	Severe	31 July - 4 Aug.	3 July 22:00 hour
18 July	Moderate	18-21 Aug.	
30-31 July	Moderate-severe	30 Aug. - 2 Sept.	31 July 21:30 hour
30 Aug.	Severe	17-21 Sept.	30 Aug. 18:00 hour
8-9 Sept.	Light	29 Sept. - 3 Oct.	

- Full bloom 24 April
- Petal fall 30 April
- Harvest 2 October
- Total number of wetness hours between 10 days after Petal fall and harvest = 1244

Orchard Randwijk
Orchard West 7 of the research station PPO Randwijk. Variety Topaz, 6 replications, 3 trees per plot. In 2002 12.8% of the fruits in this orchards where infected by SB. Weather data where collected with a Mety weather station (Bodata, Dordrecht, Netherlands) within 20 meters of the experimental plots. Cocana was used as fungicide at 0.1% (v/v) Trees where spayed with hand gun until run-off. Infection and application dates are given in Table 2. The total accumulated number of wetness hours between 10 days after petal fall and harvest is calculated as the number of hours with RH > 97%.

Table 2:
Infections according to the SB-model and application dates for the Randwijk trial

Date	According to the SB-Model		Applications of Cocana 1.0%
	Infection	First visible symptoms	
23-25 May	Severe	17-21 June	
5-6 June	Light	30 June- 3 July	
1-2 July	Moderate	24-29 July	2 July 17:00 hour
8-9 Aug.	Severe	26 Aug.- 1 Sept	11 Aug. 9:00 hour *)
8-10 Sept.	Moderate	22- 28 Sept	9 Sept. 11:00 hour

- Full bloom 24 April
- Petal fall 30 April
- Harvest 17 September
- Total number of wetness hours between 10 days after Petal fall and harvest = 1473

*) The SB infection on Saturday 9 august was recognized on Monday.

On-Farm Trials
In these trials the growers applied their normal spray program until end of blossom. As all plots consisted of the Vf scab resistant varieties Topaz and Santana there where only a few fungicidal applications made before the trials started. After petal fall

no other fungicide treatments except the treatments for the SB trial where made in the orchards.
Summer sprays where made according to the SB-Model. The sprays where applied by the grower using their tractor pulled equipment. A block of at least 4 rows wide and 20 trees long was left as unsprayed check. Trial setup and fungicide applications are listed in table 2.

Table 3:
Trial setup and fungicide applications in the "on-farm" trials.

	Varieties	Weather Station	Applications following SB-infections
Peters, Lobith (Netherlands)	Topaz	Mety	2/7 Lime Sulfur (10 kg/ha) 30/8 Lime Sulfur (10 kg/ha)
Levels, Meijel (Netherlands)	Topaz	Mety	2-7 Lime Sulfur (12.5 kg/ha) 25-7 Lime Sulfur (12.5 kg/ha) 30-8 Lime Sulfur (12.5 kg/ha)
Sturkenboom (Netherlands)	Santana	Metos Compact	2/7 Lime Sulfur (10 kg/ha) 18/7 Lime Sulfur (10 kg/ha)
Clostermann (Germany)	Topaz	Metos Compact	1/7 Lime Sulfur (12.5 kg/ha) 30/8 Lime Sulfur (12.5 kg/ha)
Prem, Keindorf (Austria)	Topaz	Metos Compact	7 June Lime sulphur (15 kg./ha) 4 July Lime sulphur (12 kg./ha) 4 Aug Cocana + copper (6 + 0,4 kg /ha) 1 Sept Cocana + copper (6 + 0,4 kg /ha) 17 Sept Copper (0,4 kg /ha)

A severe SB infection that was calculated for all trial orchards during a rainy period end of 23-25 May (24 days after petal fall) was not treated in any trial.
In the orchard Clostermann water was supplied to the trees by means of overhead irrigation several times from 19 August onwards. The weather station was not in the irrigated area and no calculations on the possible artificial SB-infections could be made.

Assessments

During summer in the Zoelmond and Randwijk trials the SB incidence was assessed several times by checking 200 fruits in the untreated plots for SB symptoms. In all trials infection incidence and severity was accessed shortly after harvest. In the Zoelmond and Randwijk trials all fruits where picked and checked for symptoms. In the other trials samples form 108 to 764 fruits per plot where used for the assessments. Incidence and severity where noted using a rating proposed by Hartman (Hartman 2000): 0 = no disease, 1= trace- 5% of fruit surface, 2= 6-25 % of fruit surface, 3= 25-50 % of fruit surface, 4= > 50 % of fruit surface. For the Zoelmond and Randwijk trials the differences in disease incidence where tested for significance using ANOVA Tukey HSD test.

Results

2003 was a very dry summer and there was much less SB compared to 2002. First symptoms where found in Zoelmond orchard on august 1st at 655 accumulated wetness hours (hours with RH>97%) starting form 10 days after petal fall. The disease incidence at harvest in orchards Randwijk and Zoelmond was only one third of that of 2002, and most infected fruits had less then 5% of their surface covered with the disease. Symptoms where only present on parts of the fruit surface that received more than average wetness time: in the stalk end, places where fruits touch each other, and places where leaves touch the fruits. Place on the fruit, shape and size of the diseased areas gave the impression that most of the spots had developed later in the season and that no secondary spread of the infections on diseased fruits had occurred.

Orchard Zoelmond

First symptoms where found beginning of august. According to the model these symptoms should have resulted form SB infections 1-2 July. (table 1)
The three treatments with Lime Sulfur that where applied according to the infection model reduced the SB incidence at harvest by 92 %.

Orchard Randwijk

During summer no SB-symptoms where found. As disease incidence and severity at harvest were very low it can not be excluded that first symptoms earlier in the season have been overlooked. The three treatments with Cocana that where applied according to the infection model reduced the SB incidence at harvest by 79%.

Table 4:
Results of the treatments with lime sulphur according the SB-model. Zoelmond 2003

		24/6	13/7	3/8	7/9	2 Oct. at harvest.					
						1= trace	2	3	4	Total	Effect
1	Untreated	0	0	3.1 a	26.6 a	39.7	21.6	1.2	0.7	63.2 a	
2	3x Lime sulfur			0.9 a	1.9 b	5.4	0	0	0	5.4 b	92 %

ANOVA. Numbers in the same column followed by the same letter are not significantly different.(P= 0.05)

Table 5:
Results of the treatments with Cocana according the SB-model. Randwijk 2003

		11 July	25 Aug.	2 Oct. 15 days after harvest.					
				1= trace	2	3	4	Total	Effect
1	Untreated	0	0	3.02	0.06	0	0	3.07 a	
2	3x Cocana			0.64	0	0	0	0.64 b	79 %

ANOVA after root transformation. Numbers in the same column followed by the same letter are not significantly different.(P= 0.05)

On farm trials
In the orchards Peters and Levels at harvest disease incidence in the untreated plots was low. The two and three treatments with lime sulfur that were that where applied according to the infection model provided complete control of the disease.
In the orchard Warmonderhof no SB had been seen in previous years. As no disease developed in the untreated plot, the SB-model could not be evaluated in this orchard.
In the orchard Clostermann on 27th of august 500 fruits in the untreated plot where checked for symptoms and only on 2 of these fruits a trace of SB was found.
Between 27th of august and harvest on 12th of September more SB symptoms developed in the treated orchard than in the untreated plot. A possible reason for this result is that the untreated plot was at the boarder of the orchard. In late august the orchard was irrigated several times by a mobile overhead irrigation system. It is possible that the border rows where not completely covered by the irrigation system. Probable artificial SB-infections caused by the irrigation could not be calculated as the weather station is in an other part of the orchard that was not irrigated.
In the untreated plot in Prem orchard in Austria almost all fruits where infected by SB. Disease severity however was much lower than in previous years. The five treatments reduced SB incidence by 72 % and raised the marketable crop form 75 to 98 %

Table 6:
Results of the treatments according the SB-Model in the "on-farm" trials in 2003.

		No .Fruits assessed	Percentage					
			1= trace	2	3	4	Total	Effect
Peters								
1	Untreated	387	1.8	0	0	0	**1.8**	
2	2x Lime sulfur on SB- Model	199	0	0	0	0	**0**	100 %
Levels								
1	Untreated	764	3.3	0	0	0	**3.3**	
2	3x Lime sulfur on SB- Model	614	0	0	0	0	**0**	100 %
Warmonderhof								
1	Untreated		0	0	0	0	**0**	
2	2x Lime sulfur on SB- Model	300	0	0	0	0	**0**	**--**
Clostermann								
1	Untreated	166	14.1	2	0	0	**16.2**	
2	2x Lime sulfur on SB- Model *)	148	22.1	5.4	0	0	**27.5**	-70 %
Prem								
1	Untreated	120	72.5	22.5	2.5	0	**97.5**	
2	6 treatments on SB- Model	108	25.6	2	0	0	**27.6**	72 %

Discussion and conclusion

In 2003 disease incidence and severity was much lower than in 2002. Weather conditions in 2003 where clearly unfavourable for SB infections. Symptoms developed mainly on parts of the fruit surface that remained longer wet than the average fruit surface: the stalk end, places where fruits touch each other, and places where leaves touch the fruits. This suggest that the symptoms found originate from longer wetness periods than those measured by the leaf wetness sensors or RH readings that where driving the infection calculations.
A management strategy in which a fungicide treatment would have been applied every 100-150 leaf wetness hours (as tested elsewhere) would have resulted in 10-14 applications as the total number of wetness hours was 1244-1473 hours. (Table 1 and 2) This would not have been reasonable for the fairly easy year for SB control that 2003 turned out to be. The current version of the SB-model calculated 5 to 6 SB-infection periods from the same dataset. With 2 to 5 fungicide treatments aimed at the severe SB infection periods as indicated by the model 72 % to 100 % reduction of SB incidence could be achieved.
Observations suggest that the first severe infection period calculated by the model 21 days after petal fall did not contribute tot the symptoms on the fruits. No fungicidal treatments where made on this infection, and the first symptoms where found not earlier than august 1st at 655 accumulated wetness hours starting 10 days after petal fall. Observations made by Barbara Kopff in 2003 and previous years in the Lake Constance area also let to the conclusion that first infections of SB on fruits occur not earlier than June. (Kopff 2003) In Western Europe it might be appropriate to start SB infection calculations 1st of June: 3 tot 4 weeks after petal fall.
The rapid build-up of symptoms in the last weeks before harvest suggest that infections in august and early September account for most of the symptoms found at harvest. This may not only be due to favourable weather conditions in late summer but most likely also to the infection potential that has grown over secondary infection cycles during summer. The feedback pictured as dashed line in figure 1 should be added to future program versions to explain the strong disease build-up in the second halve of the season caused by secondary infections.
In these trials lime sulphur and coconut soap were effectively applied after the onset of SB-infections. Post infection efficacy of Lime sulfur on apple scab was demonstrated earlier (Trapman & Drechsler-Elias 2000). Availability of fungicides with post infection efficacy is the first condition to be able to develop a management strategy based on SB infection calculations.

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