Management of primary infections of APPLE-SCAB with the simulation program RIMpro: Review of four years field trials

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Abstract

From 1993 to 1996, 53 field trials were run in different European countries to compare three strategies for the control of primary infections by apple scab *(Venturia inaequalis)*. Local practical management strategies where compared to two experimental strategies based on the information provided by the apple scab simulation program RIMpro.

In the first experimental strategy treatments were only made on moments that high numbers of ascospores infected the leaves according to the program. Averaged over the four year period this resulted in a reduction of 59% in number of treatments and 81% in amount of fungicide used during primary infection season. The strategy proved to be effective when the DMI fungicides used were fully effective and inoculum was low. In 1996 this strategy was also effective in situations with high inoculum after a treatment with copperoxychloride at bud-break to prevent early infections by overwintering conidia.

In the second strategy additional to the sprays on relevant moments as in the first strategy, protective treatments with a low dosage of the contact fungicide dithianon were made in periods of lower risk. This strategy did not reduce the number of spray rounds but let to a saving of 63% of fungicide use measured in ai./ha. This second strategy was as effective as the practical spray plan.

We concluded that the use of a simulation model as management tool can help to reduce the number of sprays and minimise the amount of fungicide used, without enhancing the risk for DIM resistance.

An integrated apple scab management strategy based on information on inoculum, susceptibility of the apple variety and the use of the simulation model RIMpro is proposed.

Introduction

Apple scab management is the most important part of crop protection in apple growing in the Netherlands. About 75% of the treatments made with pesticides have apple scab *(Venturia inaequalis)* as main target. After a recent publication of the Central Bureau for Statistics (CBS,1996) Dutch apple growers use 29,7 kg ai of biocides per hectare and year of which 86% are fungicides.

From 1990 onwards the control of apple scab in the Netherlands became more troublesome as in other European countries. Commercial orchards with more than 20 % scabbed fruit were no exception. In august 1992 and 1993 we inspected 200-500 fruits per orchard block on visible lesions on fruits (Table 1). About half of the lesions we

found will have had economic importance.

Table 1 Orchard blocks classified after the amount of scabbed fruits in august.

	No fruit scab	<2% fruits	2-<10% fruits	>10% fruits
1992 (55 orchard blocks)	7%	15%	47%	31%
1993 (68 orchard blocks)	13%	31%	31%	25%

As researchers and advisors had no direct answer to the problems the use DMI fungicides rose to extremes of more then 10 treatments per season. To manage this problem we need to know more exactly which of the 8 to 15 Mills infections periods that occur during primary infection season, are the most important, and possibly foresee these key moments in primary season.

The Dutch government approved a plan to reduce the use of biocides in agriculture (MJP-G 1990). As goal for the fruit industry was set a reduction of 23% of the chemical input 1995 and a final reduction of 44% in 2000 .

The increasing scab problem and the legal pressure to reduce fungicide input led us to explore possibilities to improve the apple scab warning system and ameliorate the management strategy.

Material and methods

RIMpro

Our aim was to develop a simple simulator for ascospore infections by *Venturia inaequalis* of apple leaves that would distinguish much more clearly between epidemic more and epidemic less important infections than Mills based warning systems do. The program should work with the weather data from simple weather stations such as those which are currently on the market (e.g. Mety, Metos, Lufft, Biomat, Climagro) and more advanced ones as Barberi and Campbell data loggers. The program should run on every PC. RIMpro has not to be a scientific model but a useful tool for growers and advisors.

In 1993 we presented the outlines of the simulation program that we use as base for a scab-warning device (Trapman 1994). Since then we only made small changes to the structure.

The program starts with green tip stage as Biofix with a pool of 10,000 immature ascospores. Driven by the weather data the program simulates maturation, discharge and infection by these ascospores. Mortality occurs at different stages during the maturation and infection process. A part of the simulation itself, the parameters can be set by the user. The program is written in Turbo Prolog, and fractional boxcar trains were used to simulate dispersion.(De Wit and Goudriaan 1974, Rabbinge,Ward and van Laar 1989)

Management strategies

The program simulated the ascospore flight reasonably well (Trapman 1994, Harzer 1997) and comparison between the infection risk calculated after Mills and RIM values

using the same data set 1993, 1994 and 1995 for the central Netherlands show a similar pattern. Therefore we started a series of field trials 1993-1996 with the aim to implement the information of the model in a scab management strategy so to reduce fungicide input without increment in scab.

RIMpro shows us higher or lower numbers of ascospores which infected per day in 'RIM values'. (RIM= Relative Infection Measure) The numbers are relative to the ascospore potential in the orchard and the susceptibility of the apple variety. We expect that in orchards with low PAD and/or little susceptible varieties treating only at moments that high RIM values occur will be enough to control apple scab. On the other hand in situations with higher risk even periods with low RIM values may give some lesions. Three control strategies were compared (for example, Table 2).

RIM strategy

Treatments were made only after high RIM values had occurred or some times just before they are expected.

Table 2 Example of the three strategies adopted at the experimental orchard in Velm (Belgium) during primary infection season in 1996 (fungicide dosages in kg per ha)

Date	RIM	RIM+ ½ Delan	Praxis
3 April	copperoxychloride 5 kg	copperoxychloride 5 kg	copperoxychloride 5 kg
11 April		Delan 0,25	
12 April			Dodine 1,75
18 April		Delan 0,25	
25 April		Delan 0,25	
2 May		Delan 0,25	
3 May	Scala 0,75+ Delan 0,25	Scala 0,75 + Delan 0,25	Scala 0,75+ captan 1,5 + sulfur 6,0
9 May		Delan 0,25	Scala 0,75+ captan 2,0
15 May		Delan 0,25	
22 May		Delan 0,25	Score 0,15+ captan 1,5
28 May	Score 0,15+Delan 0,25	Score 0,25+Delan 0,25	Score 0,15+ captan1,5
4 June		Delan 0,25	
11 June		Delan 0,25	Score 0,15+ captan 1,5

Note: Delan = dithianon 75%; captan= captan 83%; Dodine= dodine 65%; Score= difenoconazol 25%; Scala= pyrimethanil 40%; sulfur = sulfur 80%

In 1993 and 1994 for these sprays pyrifenox (75 gr. ai./ha) + dithianon (190 gr. ai/ha) was used. As we suppose that tolerance of the scab fungus to pyrifenox might be the reason for disappointing results in some cases, in 1995 and 1996 we used the most effective products available for a specific situation. At lower temperatures pyrimethanil (300 gr. ai/ha.) was used, at higher temperatures difenoconazol (50 gr. ai./ha) or flusilazol (30 gr. ai./ha). Pyrimethanil, difenoconazol and flusilazol were used in tankmix with dithianon (190 gr. ai./ha). In 1995 and 1996 in situations where a high inoculum was expected, a cover spray with copperoxychloride (1.5-2.0 kg. ai./ha) was made at bud-burst to prevent early infections by overwintering conidia.

RIM+ ½ Delan strategy

Treatments after high RIM values were made as described above, but additional protective treatments were made at 7 to 10 days interval with a low rate of dithianon to prevent infections during periods with lower RIM values. We used dithianon in 190 gr. ai./ha. This is 25% to 50% of the normal recommended rate. Our idea was that in this way we would have good control even in orchards with high inoculum and susceptible varieties with the lowest chemical input measured in kg ai. ha and with a limited use curative fungicides

Praxis strategy

Treatments were made after 'local practice'. In most cases this was a 'mixed strategy' with protective treatments on weather forecast and curative sprays after fulfilment of Mills infections period conditions were calculated by local advisory services. A wide variety of fungicides was used in this strategy.

Treatments during secondary infection season

In 1993, 1994 and 1995 all blocks were also treated during the secondary season. Treatments were made with protective fungicides. In most trials these sprays were the same for all three blocks. In some cases the two experimental strategies were treated separately with a low dosage dithianon or sulphur during summer.

Trials in different European countries

The idea for RIMpro originates from discussions in a small informal apple scab working group that consists of advisors an research workers from different European countries. Trials have been run by these people and others who became interested in the possibilities of the program. In total more than 50 field trials were run in the last four years. The field trials took place in different ways. A smaller part of the trials was done as replicated field trial in smaller blocks. Most of the trials was done in a very practical manner. The strategies where compared in single up to four replications in orchard blocks from 0,2 to 1,0 hectare in size. Most of the trials were sprayed with tractor pulled sprayers. Observations where made several times during primary and secondary infection season by checking 100 to 400 shoots. Number of infected leaves and lesions per infected leave was noted. In some trials only the percentages infected shoots was noted. In most trials shortly before or after harvest at least 500 fruits per block where inspected on scab lesions.

Weather data

The weather data to run the model where taken form an on site or nearby weather station. To be able to work with different types of weather stations RIMpro was set up to read different types ASCII data files.

Results and discussion

1993 and 1994

In 1993 we had 7 trials in 3 countries (Netherlands, Belgium, and France). In 1994 we

had 19 trials in 6 countries (Austria, Belgium, Germany, Italy, Netherlands and Poland). The "RIM+ ½ Delan "object was treated as often as the praxis scheme in both years, but the saving measured in kilogram active ingredient was 72% in 1993 and 76% in 1994. (Table 3 and 4). Spraying only after high RIM values the number of sprays was halved, and the amount of fungicide used was only 12% to 15% of the amount used in the praxis plan.

Table 3 Average values and standard deviation in the brackets in 1993 trials.

	RIM	RIM +½ Delan	Praxis
Number of treatments in primary infection season	4.4 (0.7)	9.7 (1.7)	8.9 (2.6)
Amount of fungicide used during primary infection season (kg. ai./ha.)	1.9 (1.0)	3.5 (1.1)	12.7 (6.3)
Number of lesions on 100 shoots in June	70 (61)	30 (33)	35 (37)
Percentage of apples with scab lesions at harvest	3.9 (6.2)	0.8 (1.1)	1.4 (2.6)

Table 4 Average values and standard deviation in the brackets in 1994 trials.

	RIM	RIM +½ Delan	Praxis
Number of treatments in primary infection season	2.5 (1.0)	6.3 (2.4)	6.9 (1.4)
Amount of fungicide used during primary infection season (kg. ai./ha.)	0.7 (0.4)	1.4 (0.6)	5.8 (3.3)
Number of lesions on 100 shoots in June	55 (105)	7 (8)	14 (20)
Percentage of apples with scab lesions at harvest	2.3 (3.3)	0.8 (1,0)	0.8 (1.0)

The 'RIM+Low Delan' strategy was as effective as the praxis spray plan in both years. However treating only after high RIM value was less effective. The results were worst in orchards with high inoculum and high susceptible varieties. We see several possible reasons for this:

1. For some locations the 1993 and 1994 version of RIMpro 'predicted' the end of ascospore discharge too early and as a result we missed a last primary infection.
2. Treatments after less important infections (low RIM values) are deliberately left out.
3. In orchards with high inoculum overwintering conidia may have let to early primary infections.
4. low temperatures in April 1994 let to reduced uptake of DMI fungicides and reduced effectively of the treatments.
5. tolerance of the scab fungus to DMI fungicides reduced the effectiveness of the curative sprays in some orchards.
6. after the first lesions became visible we did not immediately change to a routine spray program with protective fungicides.

1995 and 1996

On basis of the results in 1993 and 1994 the structure of RIM pro was slightly changed and the user interface was improved. To avoid bad results caused by tolerance of the fungus for some DMI fungicides we used only reliable curative compounds as described

above. In case of high inoculum one treatment with copperoxichloride was made at bud burst.

In 1995 we had 19 trails in the same countries as 1994. Additional trials in Poland, Italy and Austria are not reported here as informations are incomplete. Preliminary results are given for 9 trials in 1996. As in 1993 and 1994 the RIM+ ½ Delan plots were as often treated as the praxis scheme, but the reduction in fungicide use was 63% in 1995 and 38% in 1996. In the RIM plots less than half the number of treatments was needed in both years and the saving in fungicides was 82% in 1995 and 71% in 1996 (Tables 5 and 7). In 1995 highest disease incidence on leaves and fruits was found on the scab susceptible varieties Summerred and Jonagold at research centre De Schuilenburg and in one of the two trials run by the 'Suedtiroler Beratungsing' in Brixen. (Table 6) At the Schuilenburg inoculum has been very high. In autumn 1994 on the variety Elstar 23.5-57.5% of the leaves had one or more lesions. In the trial in Brixen an infection must have occurred at the end of primary infection season. Whether we stopped spraying too early or there was a technical failure is not cleared. Most lesions were found in the standard scheme. In all other cases disease incidence was limited and the technical results of the three schemes where comparable.

Table 5 Number of sprays and amount of fungicide used (kg ai./ha) in primary infection season in 1995

Location	RIM		RIM ½ Delan		Praxis	
	No.	kg ai	No.	kg ai	No.	kg ai
Exp. Orchard De Schuilemburg (NL)	4	3.2	7	3.7	7	4.7
Herveld (NL)	4	2.2				
Eck en Wiel (NL)	4	6.1			10	13.0
Hemmen (NL)	3	3.7			11	13.3
Marknesse (NL)	4	3.2			14	8.5
Kloetingen (NL)			12	9.8	12	23.5
Tuil (NL)			15	9.2	17	36.3
Zeewolde (NL)			14	5.8	14	17.6
Dronten (NL)			12	4.7	12	18.0
Exp. Orchard Velm (B)	4	2.2	12	4.2	8	15.0
Werm (B)	6	2.1			10	7.0
Exp. Orchard Ahrweiler (D)	4	0.8	8	1.6	8	10.9
Holzweiler (D)	4	0.8	8	1.6	8	10.9
Neustadt (D)	1	0.1	5	1.0	6	2.0
Frankfurt a/d Oder (D)	4	2.			6	3.6
Bodensee (D)	3	2.0	12	5.2	12	7.6
average	*3.8*	*2.4*	*10.5*	*4.7*	*10.3*	*12.8*

Table 6 Number of scabbed leaves o f 100 shoots or % shoots with scab lesions after primary infection season in June and incidence of fruit scab at harvest (%) in 1995.

Location	Variety	RIM		RIM+ ½ Delan		Praxis		control untreated
Exp. Orchard De	Summerred	36	(4.6)	67	5.5	31	(2.7)	
Schuilemburg (NL)	Jonagold	20	(5.0)	13	(3.3)	7	(3.1)	
	Elstar	10	(1.1)	9	(0.9)	9	(0.2)	
	Cox's O.P	2	(0.5)	2	(0.5)	3	(0.4)	
	Boskoop	1	(1.3)	2	(1.0)	1	(0.8)	
	Alkmene	1	(0.3)	0	(0.4)	0	(0.1)	
Herveld (NL)	Elstar	10	(0.8)			1	(0)	
Eck en Wiel (NL)	Jonagold	4	(0.6)			0	(0.2)	
Hemmen (NL)	Jonagold	16	(1.2)			14	(0.4)	
Marknesse (NL)	Golden	2	(0.5)			0	(0)	
	Cox's	0	(1.4)			0	(0)	
Kloetingen (NL)	Jonagold			0	(0)	0	(1.8)	
Tuil (NL)	Jonagold			0	(0)	0	(0)	
Zeewolde (NL)	Elstar			1	(0.2)	0	(0)	
Dronten (NL)	Elstar			0	(0.7)	0	(0)	
Exp. Orchard Velm	Jonagold	5	(0.8)	1	(0.8)	4	(1.4)	
(B)	Elstar	3	(0)			1	(0)	
	Idared	0	(0.8)	0	(0.6)	0	(0.4)	
	Cox's		(0)		(0)		(0)	
	Alkmene	0	(0)	0	(0)	0	(0.4)	
Werm (B)	Summerred	13	(0)			2	(0)	
	Jonagold	7	(0.4)			0	(0)	
	Boskoop	0	(0)			0	(0)	
Exp. Orchard	Rubinette	0-1.6 %	-	0 %	-	1.6 %	-	5 %
Ahrweiler (D)								
Holzweiler (D)	Jonagold	0.5 %	-	1.5 %	-	0.5 %	- -	-
Neustadt (D)	Jonagold	1 %	-	0 %		1 %	-	18 %
Frankfurt a/d Oder	Jonagold	0	(0)			0	(0)	-
(D)	Elstar	0	(0)			0	(0)	
Bodensee (D)	Jonagold	0	-	0	-	0	-	124
Lana (I)	Jonagold	0	-	0	-	0	-	-
Brixen (I)	Jonagold		-		-		-	
	May 15	0		0		0		540
	June 9	179		100		231		

In 1996 we expected a high inoculum in several orchards. We could not calculate PAD as we did not collect information on number of lesions per shoot, leave area index and leaf degradation, but Table 8 shows the number of infected leaves per 100 shoots in the

last counting in 1995. In all these situations calculation of PAD should probably have let to a figure higher than 600. Subsequently according to MacHardy (MacHardy 1994) no sprays could be left out during primary infection season. Despite this high inoculum in all but one orchard the primary infection level (observations in July) was low (Table 8). The orchard 'Hemmen' was a multiple row orchard with high inoculum and slow leaf degradation. In July 20% (estimated) of the orchard floor was still covered with old leaves. In the RIM and the Standard scheme a comparable amount of disease developed.

Conclusion

Our trials show that the information provided by RIMpro helps to optimise the sprayplan and allows a reduction of the number of treatments and of the amount of fungicide.

We conclude as Madeleine Bühler (Bühler 1995), that a IDM (Integrated Disease Management) strategy can only be successful if the curative fungicides used are fully effective. We also found that our reduced strategy was less effective in situations with higher inoculum, however this is only the case for the more susceptible varieties. In the 1996 trials even with high inoculum and susceptible varieties we had good technical results with our reduced strategy. This seems to be in contrary to the findings of Bühler (Bühler 1995) , vd Scheer (vd Scheer 1994) and MacHardy(MacHardy 1994). We explain this by the fact that we used a spray with copperoxychloride at bud-break to prevent conidial infections, and the less uncertain weather conditions in 1996.

Table 7 Number of treatments and amount of fungicide used (kg ai./ha) during primary infection season in 1996

	RIM*		RIM+ ½ Delan		Praxis	
	No.	kg ai	No.	kg ai	No.	kg ai
Velm (B)	3	3.2	12	4.9	7	15.8
Schuilenburg (NL)	4	4.7	9	5.6	9	7.0
Herveld (NL)	4	2.7				
Hemmen (NL)	3	3.5			7	5.2
Eck en Wiel (NL)	4	4.8			8	6.9
Marknesse (NL)	3	2.1			9	10.2
Bodensee (D)	2	0.5			8	7.0
	3	1.2				
South Tyrol 1 (I)	3	2.0			5	7.1
South Tyrol 2 (I)	3	0.7			7	10.6
average	*3.2*	*2.5*	*10.5*	*5.3*	*7.5*	*8.7*

*: Including a spray with copperoxychlorid (3-5 kg/ha) at bud break for orchards with high inoculum. to prevent conidial infections.

RIMpro is now used in practice by a steady growing group of growers and advisors. Their comments will be used to improve the technical performance of the program and

the user interface.

Proposed integrated scab management strategy

RIMpro indicates the relative importance of primary infections of apple-scab. Used as regional warning system important individual orchard parameters as inoculum and susceptibility of the apple variety can not be taken in account. These have to be considered by the grower himself. Based on our field experience and technical considerations we can characterise three situations (Table 9) and describe for each an adapted scab management strategy:

Situation 1 Risk is low and we advise to spray only when RIM values over 300 are expected or have occurred.

Situation 2 We advise to treat with a reduced dosage of dithianon when rain is expected and to make curative treatments when high RIM values have occurred.

Situation 3 Scab management will be difficult. Primary infections may be caused by overwintering conidia and even treating all Mills infections is not always enough effective. Spraying urea (5%) just before leaf fall and applying copper at bud-break may bring you back in situation 2. Spray protective fungicides just before rain and use curative compounds after high RIM values occur.

Table 8 Number of scabbed leaves on 100 shoots in autumn 1996, and after primary infection season in June-July 1996

		1995	RIM	RIM+ ½ Delan	Praxis
Velm	Jonagold	October: 18	2	1	1
	Idared		1	0	0
	Elstar		0		0
	Alkmene		0	0	0
Schuilenburg	Jonagold	October: 230	0.75	0.5	0.25
Herveld	Elstar	August: 208	0		0
Hemmen	Jonagold	> 100	36		21
Eck en Wiel	Jonagold	October: 1340	0		0
Marknesse	Golden	>100	0		0
	Cox's OP		0		0
Bodensee	Elstar		6		2
	Elstar		1		
South Tyrol 1	Gala		0		0
South Tyrol 2	Golden		3		1
	Jonagold		1		0

Table 9. Scab risk situation and advised scab control strategy considering past fall scab and apple cultivar susceptibility. (Details of strategies in text)

	Susceptibility to scab			
	Low	Moderate	Susceptible	Highly
Scab on shoots last autumn	Alkmene Discovery Katja	Boskoop Cox's O.P Elstar	Jonagold Golden Breaburn	Summerred Gloster, Gala Arlet1, MacIntosh
No scab	low 1	low 1	low 1	medium 2
Little	low 1	1-2	medium 2	high 3
more than a few spots	Medium 2	high 3	high 3	high 3

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