Riverland Wine Industry Development Council Inc.

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Grape and Wine Research and Development Corporation

A strategic review: the first steps in establishing low input viticulture regimes … rationalising powdery mildew control in Riverland vineyards





FINAL REPORT to
GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

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Principal Investigator: **Peter Magarey**
Co-Editors: Bob Emmett, Tim Smythe and Justin Dixon

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Editor Details:

Peter A Magarey
(formerly SARDI, PO Box 411, Loxton, SA 5333)
(now) Magarey Plant Pathology
PO Box 220, Loxton, SA 5333
Phone: (08) 8584 6386
Email: pmagarey@riverland.net.au

Dr Robert W. Emmett
Victorian Dept Primary Industries
PO Box 905, DPI Mildura Centre, Victoria 3502
Phone: (03) 5051 4555
Fax: (03) 5051 4523
Email: Bob.Emmett@dpi.vic.gov.au

Justin Dixon
South Australian Murray-Darling Basin Resource Information Centre (SAMRIC)
PO Box 441, Berri SA 5343
Phone: (08) 8580-8518
Email: justindixon@samric.org.au

Tim Smythe
Riverland Wine Industry Development Council (RWIDC)
PO Box 520 Berri SA 5343
Phone: (08) 8582-2952
Fax: (08) 8582-3309
Email: tim.smythe@riverlandwine.org.au

Co-Authors and Details:

Michelle Moyer
NYSAES, Cornell University, Geneva, New York, USA, 14456
Email: mmm78@cornell.edu

Adam Pietsch
CCW Co-op. Ltd, Berri, SA, 5343
Email: adam.pietsch@cwines.com.au

Peter Burne
formerly CCW Co-op. Ltd, Berri, SA, 5343

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2. Executive Summary

Most Riverland vineyards are sprayed frequently to control powdery mildew but a single spray of sulphur across the region cost nearly $1m. In efforts to reduce these costs, improve control of the disease with fewer sprays and reduce the carbon footprint in vineyards, spray diary records from CCW Ltd, Berri, SA, and McGuigan's Wines, Loxton, SA, for several varieties for season 2006/07 were overviewed. Several thousand individual patch records were assessed initially, prior to a sub-sample of 137 Chardonnay spray diaries being reviewed in more detail. To assist this review, a vineyard spray program evaluator was devised and used to rapidly assess the effectiveness of sprays applied. Disease scores from the evaluator were compared with in-field disease assessment ratings made by wineries just prior to harvest.

Generally speaking the spray programs listed in the diaries controlled powdery well with minimal impact on the sale of the crop. An average of 7 sprays were applied/season. There was however, a large range in the number applied (from 2 to 13 sprays were applied in that season) with varying degrees of success in controlling powdery from within that range. Some growers achieved excellent control with as few as four sprays, while others sprayed twelve or more times and achieved poor control. There was no correlation between the number of sprays and the level of control.

Only a few patches (6% in number, accounting for 3% of the area) had levels of disease sufficient for the winery to reject the crop. This means that most growers did an acceptable or better job in controlling the disease, even though the outcome might have been achieved with fewer sprays.

Most growers (73% of the patches, accounting for 81% of total area surveyed) applied less than eight sprays but had insignificant amounts of mildew in their vineyard patch pre-harvest. More sprays were not better meaning that, on average, no better control of powdery was achieved by the application of more sprays. This suggests that the additional sprays applied by the 25% of growers, were unwarranted.

The probable explanation is that it was not the number of fungicides but their timing and/or coverage that was critical in controlling powdery mildew.

Many spray programs lacked optimum timing but all used fungicides effective against powdery. Most growers used appropriate techniques, at least as far as the data permitted assessment of this, but the spray diary data (understandably) did not include important detail of the vineyard inoculum loads nor of the efficiency of spray machinery in reaching the targeted vineyard canopy.

Analyses showed that many growers had difficulty in applying the modified Eichorn-Lorenz system of rating the seasonal stages of vineyard growth. Some form of teaching this system would be appropriate to assist growers better assess vine canopies in delivering more refined management of grapevine powdery mildew.

Poor management within vineyards was generally related to isolated patches. Spatial presentation of the spray diary data indicated a clumped distribution of vineyard patches with high levels of disease. This may have arisen from some disease related factor such as initial inoculum loads in those patches, some local micro-climatic factor, or other cultural feature. However, it more likely arises from some social factor associated with vineyard managers' understanding and/or application of optimum powdery mildew strategies.

It was of significance to note higher levels of powdery mildew in vineyards with undervine sprinkler irrigation in contrast to vineyard patches with overhead or more significantly, drip irrigation systems. The higher levels of disease may be related to the higher humidity supposedly associated with vineyards with undervine irrigation.

Analyses of the spray diaries indicated that improved spray programs with fewer sprays/season can be adopted for better control of powdery mildew in the Riverland. As few as 2-4 sprays/season may be achievable, allowing environmentally cleaner spray programmes and lower cost of controlling powdery mildew. A better understanding of the epidemiology of powdery mildew's development and the influence of canopy microclimate may improve resolution in the timing of sprays.

Assessing spray diaries helped to identify areas for improvement in managing the disease. Analysis of more years and varieties would provide a better profile on the activity of the Riverland industry in managing powdery mildew. An easily used, standardised disease rating system would improve the quality of disease assessments made by winery staff and assist the analysis of spray diaries by growers, vineyard monitors, managers and researchers.

The *vineyard spray program evaluator* developed in this project could be used to:

1) rapidly review spray diary records for other seasons or other regions.
2) develop industry bench-marks for fungicide use in the control of powdery mildew.
3) evaluate planned spray schedules for effectiveness and weakness before sprays are applied.
4) determine which spray schedules are effective and which are not; and
5) determine the minimum number of sprays for improved control of mildew, reduced fuel and chemical use, lower costs and reduced carbon emissions in Australian vineyards.

The *vineyard spray program evaluator* has further potential as an online module in *CropWatchOnline.com* for growers, vineyard managers, consultants and others to assess their own records

Initial results from the current project suggested there is great opportunity to move to strategic spray programs with fewer well-timed sprays for better management of powdery mildew. Analysis of additional spray schedules would help define a valid bench mark for change before introducing a structured approach to improved disease control across the region.

Not-withstanding, it seems realistic to set course to reduce the number and improve the effectiveness of sprays growers apply for powdery mildew in the Riverland. In the spray diaries investigated, many growers consistently achieved control with as few as four sprays per season. It is recommended that this be set as a preliminary benchmark for the Riverland grape industry.

3. General Report

3.1. Introduction

Many Riverland growers were spraying frequently for powdery mildew. Most achieved good control but the cost to the Region of applying many sprays per season was significant. A single spray of say, sulphur, cost the Riverland around $1,050,000. Because most vineyards were sprayed between five to eight times, the total cost amounted to between $4,000,000 to $8,000,000/season. The frequent spraying had additional impact through the increased accounting of carbon credits against the fuel consumed by the spray machinery.

With the wine industry in recent years falling on hard times there was considerable pressure to realise cost savings in production. Increasingly, additional pressure will be applied to reduce the emission of greenhouse gasses.

From purely an economic point of view, the above figures gave indication of the potential for a targeted approach to the management of powdery mildew to reduce the Region's reliance on spraying and, instead, build a strategy for possible eradication of the disease within localities.

The details maintained in growers' spray diaries offered potential to evaluate spray programmes and to assess where efficiencies might be made in reducing the financial and environmental costs of control. A vineyard disease calculator for powdery mildew and regional assessment offered great potential to better rationalise Riverland spraying practices in controlling the disease.

In assessing apparent failures and successes in current spray programs, the Riverland viticultural sector was in a good position to develop a platform for the strategic management of powdery mildew inoculum. Work of this nature had the potential to provide tangible results for an industry under increasing demand for low (critical) input viticulture and sustainable management.

3.2. Aims

The aims of the project were:

- Analyse vineyard spray diaries and associated winery vineyard disease records;
- Investigate control successes and failures;
- Assess the potential for a lower input spray regime.

Matters of particular interest were:

- Develop an understanding of what drives good powdery mildew control;
- Determine what causes the failures; and
- Determine scope for change (disease control and financial performance)

3.3. Methods

A team of investigators collected data from paper-based spray diaries from season 2006/07, entered the details to computer, devised a means of rapidly assessing each spray record in each diary for accuracy and potential effectiveness, and then analysed the data set. A vineyard spray program evaluator was constructed then used to score each spray record. This system allowed rapid comparison of the effectiveness of spray details against the disease rating given to each vineyard by wineries just before harvest that season.

From this, an assessment of the number and effectiveness of sprays for powdery in Riverland vineyards was made.

For detail of these methods, the vineyard spray program evaluator, and of outcomes of the analyses, see the full scientific report on this project in Appendix 1.

3.4. Results

Spray diaries relating to the control of powdery mildew in Riverland vineyards during 2006/07 were reviewed from 1206 Chardonnay, 1,450 Shiraz and 13 Verdelho patches. In these records, a system of rating vineyards for powdery mildew incidence and severity was undertaken by the winery as shown in Table 1.

Table 1. Powdery Mildew Ratings

PM Rating	Powdery Mildew Assessment
0	None found
1	Trace on leaf/bunch stem/pedicle or insignificant.
2	Trace on fruit or occasional hotspot but not an issue.
3	Bad on leaf/bunch stem/pedicle.
4	Fruit dropped/part of patch not picked/deductions.
5	Rejected.

A next step in the investigation involved detailed assessment of the spray diaries from 160 of the Chardonnay growers associated with CCW Cooperative Ltd. These accounted for approximately 250 Ha in the Riverland region. The analyses of disease outcomes showed that powdery mildew was well controlled in 73% of the Chardonnay patches, receiving a Disease Rating of 2 or less (Figure 1). These patches accounted for 81% of the total area from this sample.

This showed that a large majority of Chardonnay growers achieved excellent control of powdery in their vineyards. Only 6% of the growers failed to control the disease and had their fruit rejected (Disease Rating = 5), accounting for only 3% of the area.

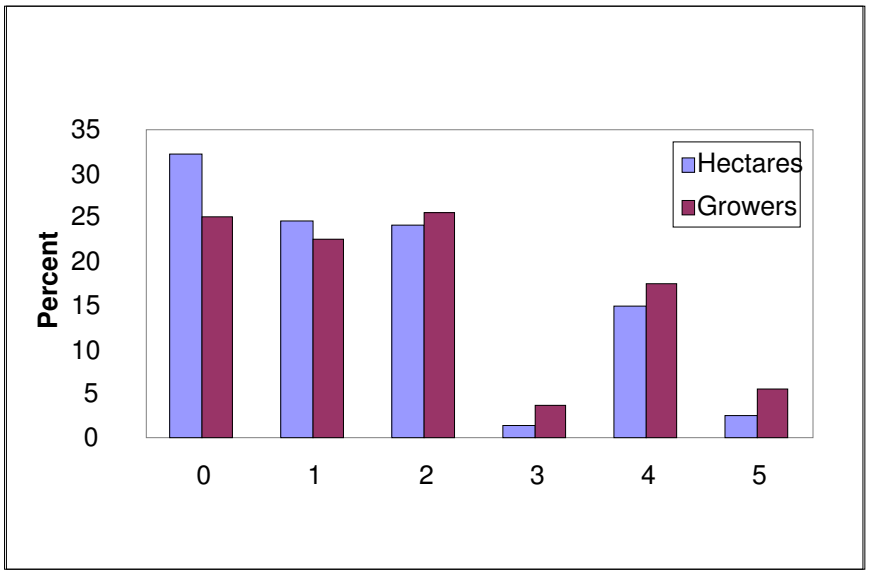


Figure 1: The Disease Rating from the winery's assessment for powdery mildew on the fruit prior to harvest 2006/07 for selected Riverland Chardonnay growers, indicating percent growers and hectares receiving each Disease Rating.

Next, individual spray programmes were analysed for their effectiveness in powdery mildew control. The programs from 113 growers representing 137 patches showed that individual spray programs were extremely variable. Table 2 shows how much the numbers of sprays applied varied between growers. Some growers sprayed for powdery mildew only twice in the season while others sprayed 13 times.

Table 2. Spray Summaries for Chardonnay in the Riverland, 2006/07.	
Minimum Sprays Applied	2
Maximum Sprays Applied	13
Most Common # of Sprays	7

Of the total number of growers, 25% sprayed less than six times. However, although a majority (75% of the surveyed growers) sprayed less than eight times, a reasonable proportion (25%) applied more than eight sprays (Table 3).

Table 3. Percent of growers applying less than indicated sprays.	
% Growers	**# of Sprays**
25	< 6
75	< 8
25	> 8

The variability in these numbers indicates a lack of recognition as to when a powdery mildew spray should have been applied, resulting in many growers over-applying products. The outcome was increased (and may be unnecessary) expense for fungicide, petrol, labour and water. This extra spraying may have been caused in part by poor timing of the applications which led to the need for additional sprays in attempt to catch up what was missed.

This highlights the need for better education and/or a management tool to help growers decide '*when to spray and how many sprays to apply'* for reliable control of powdery.

Spray Timing Scores:
When it comes to managing powdery mildew, at least some spraying is needed. Unfortunately for many growers, this often translates to 'applying more to be sure'. But do 'more sprays' equal 'better control'? The answer is, 'No', and Figure 2 shows us why?

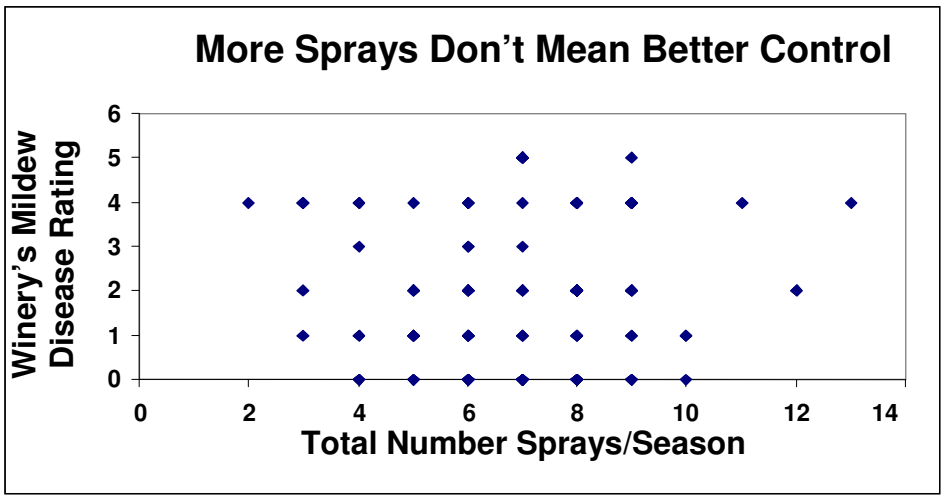


Figure 2. Plot of the number sprays applied for powdery mildew/patch for cv. Chardonnay, 2006/07, shows better control of powdery was not achieved when more sprays were applied.

There was no connection between the total number of sprays and the disease ratings in patches. Some patches with Rating 4, received the minimum number of sprays (2), while others received the maximum number (13). This was also true for other patches with 3 to 11 sprays. Hence, more sprays did not give better control. Instead, more appropriate timing of sprays was needed for best control.

A closer look at the data in Figure 2 showed that Chardonnay patches with excellent disease control, that is with a mildew disease rating score of zero, received as few as four and as many as ten sprays. Depending on the situation in each vineyard, this showed that in Riverland Chardonnay vineyards, the best control for powdery mildew might be achieved with as few as four sprays. In more tolerant varieties, this number might be even less.

To check this in more detail, a Spray Timing Score was developed to rate the date of each spray within each spray diary in relation to the ideal timing for good disease control. A scale of 1-20 was established, based on knowledge of powdery mildew epidemiology (that is, how the disease spreads across a vineyard during a season) and the susceptibility of vines to powdery mildew. From this, a theoretical 'best timing' strategy of spraying was developed. A patch with a score of less than 6 was considered to have very good spray timing, and a patch with 1 to 3, excellent timing. To the contrary, patches with very poorly timed sprays, often missing key target windows for powdery mildew's development, was given a score of 10 or more. The detail of this is explained in Appendix 2.

The analyses of Spray Timing Score in Riverland spray diaries showed a 'two-peak' distribution in (Figure 3). Most patches were in one of two extremes: about 45% of growers performed very well (with Spray Timing Scores ≤ 6) while nearly 55% had very poor spray timing (with scores ≥ 10).

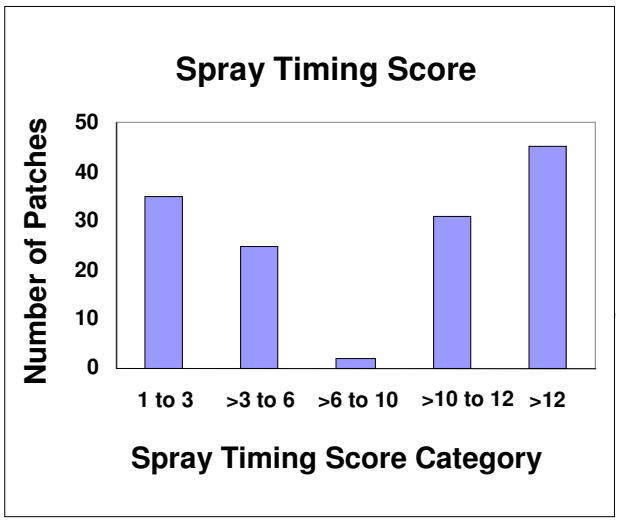


Figure 3- Distribution of patches in Spray Timing Score categories in relation to a theoretical optimum spray schedule – the system ranked scores from 1 to 20. See Appendix 1 for details.

So what does this indicate?

While a large proportion of growers were, we suppose, well educated and vigilant with their spray timing, there was a slightly larger proportion who appeared to lack either the knowledge of powdery mildew disease or the confidence to back their judgement on that knowledge. Either way, the second group timed sprays poorly and failed to control the disease efficiently.

Figure 4 shows another summary of these data by clumping the spray rating for each patch into one of two groups, depending the rating score achieved.

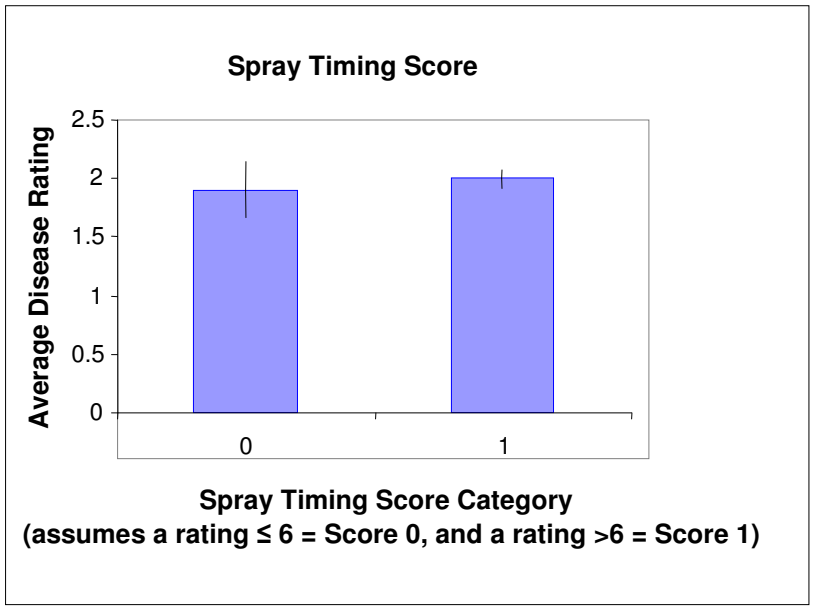


Figure 4- Summary of spray timing categories and associated Disease Ratings. See Table 1 for details.

This showed there was no significant difference in the average Disease Rating between the scores for 'Good', and 'Poor' spray timing. However, there was variation of Disease Rating within a Spray Timing Score category. Patches with a mildew Disease Rating of zero (excellent control) achieved this with both a (few) well-timed sprays or with (many) poorly timed applications. And patches with a high Disease Rating were sometimes sprayed with well-timed applications, without apparent effect.

Occurrence of patches with a low Spray Timing Score but a high Disease Rating, initially indicated a lack of correlation between the two factors. However, even a properly timed spray can not provide good disease control if the selected pray treatment (choice of product and spray rate) and/or spray technique (spray coverage deposition and canopy penetration) are inadequate.

Spray Treatment and Technique Scores:
The final analysis performed on the grower spray diaries was to score each record for spray treatment and spray technique. 'Treatment' was judged on the appropriate choice of fungicide and rates of application at a particular time. 'Technique' was judged on use of an appropriate water volume, and according to the number of other products tank-mixed with the selected powdery mildew fungicide. For 'Technique', favourable scores were given to those sprays containing less than two products in the tank. Moderately unfavourable scores were for 2-5 products. Use of more than six products was considered extremely undesirable because of the potential for incompatibility between products.

All growers, in all patches, and at all sprays, received a perfect score for 'Treatment', indicating that appropriate rates of powdery mildew fungicide were applied. Overall, most growers also received good scores for 'Technique' (Figure 5). However, unwisely, eight growers tank-mixed more than six products, but this was a rare occurrence. Even more rare was a patch with more than two sprays scoring poorly for Technique.

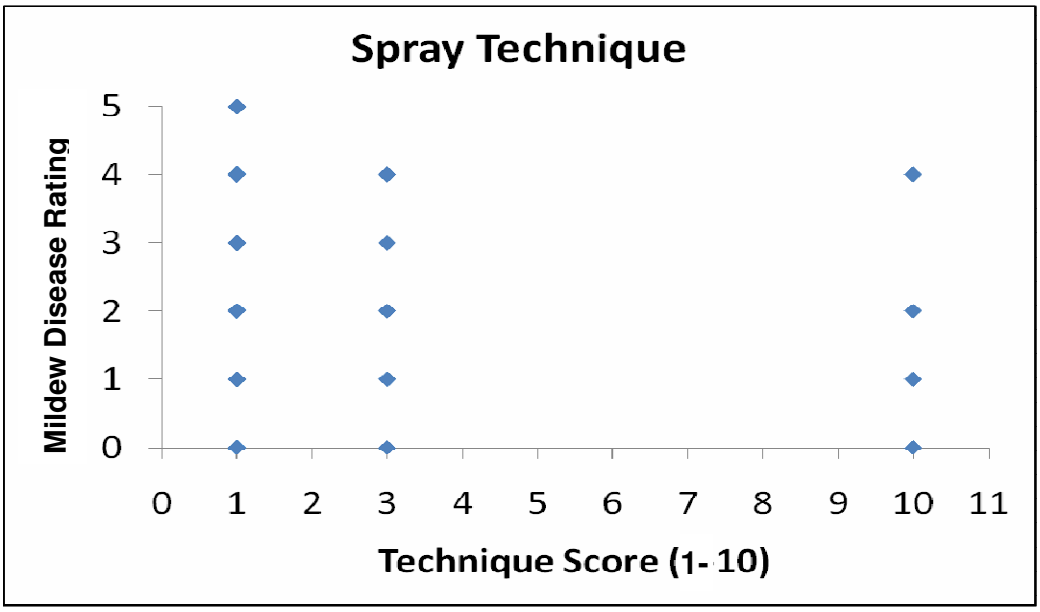


Figure 5- Summary of Spray Technique Scores and associated Disease Ratings. See Appendix 1 for details.

Eichorn-Lorenz (E-L) Growth Stage

In undertaking this assessment of spray diaries, various educational issues were highlighted. Among these were those relating to the inability of many growers to use the Eichorn-Lorenz (E-L) system to correctly identify vine growth stages. It became clear that many growers had a limited knowledge of this system. Most could assess the flowering stage but there was considerable variation in their capacity to assess (or accurately record) the other stages. If this system is still to be used in spray diaries, a better understanding of the system is needed.

Vineyard Spray Program Evaluator

Assessment of the timing of sprays was difficult initially but this was addressed by constructing a finely tuned *vineyard spray program evaluator.* This processed and scored large numbers of spray records in digital form, and overcame the lack of accuracy and consistency in assessments of E-L growth stages.

Within the *evaluator*, the theoretical ideal spray dates were set and each spray diary was assessed against that assumed regime.

Appendix 2 provides full details of its construction and use.

Spatial Analyses of Spray Diary Data

A geographical representation of the spray diary data (in a confidential assessment) **showed that there was a grouping of patches with poor control in several localities. The** cause of these anomalies was not known but could have related to a number of issues, including perhaps a locally high level of powdery that made control difficult, or may be some sociological factor relating to the approach the local growers took in attempting to control disease, or perhaps there was some local meso-climate and cultural influence which was active there. Association of these patches with the same few growers might be the main explanation – meaning the same inefficient strategies may be being applied to these vineyards.

Influence of Irrigation Practices on Severity of Powdery Mildew

Of significant note, higher incidences of powdery mildew with a Disease Rating of 4-5 (see Table 1) occurred in patches with under-vine sprinkler irrigation as compared with drip irrigation. This was observed in the detailed assessment of records from both Chardonnay (Table 4) and Shiraz growers. There were significantly more vineyards with a disease rating of 4 or 5 in under vine sprinkler irrigated patches than as an higher incidence of vineyards

Table 4. Disease Rating associated with irrigation practices in a sample of Chardonnay vineyards 2006/07 (n=137).

Powdery Mildew Disease Rating	% Patches with Drip Irrigation /Total # (n=23)	% Patches with Under Vine Sprinklers /Total # (n=70)	% Patches O/Head Sprinklers /Total # (n=36)
0	35%	38%	25%
1-3	12%	49%	31%
4-5	3%	**73%**	17%

3.5. Future Focus

Evaluation of Spray Diaries

- Improved spray programs with fewer sprays/season can be adopted for better control of powdery mildew in the Riverland;
- As few as 2-4 sprays/season may be adequate, allowing environmentally cleaner spray programmes and lower cost of controlling powdery mildew;
- A better understanding of the epidemiology of powdery mildew's development and the influence of canopy microclimate may improve resolution in the timing of sprays;
- The Spray Treatment and Technique Scores appear to be good in the Riverland but the data available in the spray diaries did not allow useful assessment of vineyard inoculum levels nor of the spray coverage achieved;
- Poor management within vineyards was generally on isolated patches;
- The high winery ratings for disease may be related to poor spray coverage or improper sprayer maintenance;
- It appears that there is an education gap in disease management with growers. The findings from research programmes in recent seasons is yet to be fully conveyed to Riverland growers;
- Assessing spray diaries helps to identify areas for improvement in managing the disease in Riverland vineyards;
- Analysis of more years and varieties is needed for a better profile on the activity of the Riverland industry in managing the disease;
- An easily used, standardised disease rating system would probably improve the quality of disease assessments made by winery staff and assist the analysis of spray diaries by growers, vineyard monitors, managers and researchers.

The Vineyard Spray Program Evaluator

The *vineyard spray program evaluator* developed and use in this project could also be used to:

1) rapidly review spray diary records for other seasons or other regions.
2) develop industry bench-marks for fungicide use in the control of powdery mildew.
3) evaluate planned spray schedules for effectiveness and weakness before sprays are applied.
4) determine which spray schedules are effective and which are not; and
5) determine the minimum number of sprays for improved control of mildew, reduced fuel and chemical use, lower costs and reduced carbon emissions in Australian vineyards.

The *vineyard spray program evaluator* has potential to be developed as an online module in *CropWatchOnline.com* for growers, vineyard managers, consultants and others to assess their own records.

The project looked at spray diary records and compared them with in-field disease assessment ratings. Data for the project had been gratefully received from CCW and McGuigan's Wines.

Generally speaking the spray programmes listed in the diaries had controlled powdery to levels with minimal impact on the sale of the crop. There was however, a large range in the number of sprays applied and varying degrees of success with control from within that range. Some growers achieved excellent control with as few as four sprays while others sprayed twelve or more times and achieved poor control. There was no correlation between the number of sprays and the level of control.

The assessment revealed there were two groups of growers: those who sprayed lots and those who didn't. Either way, the correlation between timing and disease control was not strong, meaning that there was a lot of variation in what individual growers did in attempting to control the disease.

Treatment, likewise, was hard to assess. Those who had used a tank mix of greater than six chemicals were marked down but there was no correlation with the level of disease control achieved.

The review also helped identify other aspects with potential for improvement of control measures for powdery mildew. For instance, there was no correlation between the timing and treatment (ie the selection of registered fungicides) in control strategies and the outcomes ranged greatly in success rate. Means of achieving adequate spray coverage and an improved knowledge of the management of inoculum reservoirs appear to be issues that need addressing. This includes aspects such as where does the disease come from: flag shoots and/or cleistothecia?, when does the over-wintering inoculum begin to spread? and when is it best to begin spray applications to control the disease?

Regarding the scope for change within the industry, initial results suggest that there is great opportunity to move to strategic spray programs with fewer well-timed sprays for better management of powdery mildew. More data analysis of spray schedules as was undertaken in this project would be useful especially to review data from at least a second season. This would help define a valid bench mark for change before introducing a structured approach to improved disease control across the region.

Not-withstanding, a course set to reduce the number and improve the effectiveness of sprays applied for powdery mildew in the Riverland seems realistic. In the spray diaries investigated, many growers consistently achieved control with as few as four sprays per season. It is recommended that this be set as a preliminary benchmark for the Riverland grape industry.

3.6. Extension to Growers

The findings of this project have been communicated to grapegrowers in a number of workshops and seminars attended by the first and/or fourth authors and in services they have provided Riverland grapegrowers.

These include workshops presented in Margaret River and Frankland in Western Australia in August 2009, in the Hunter Valley in October 2009 and in meetings of the Riverland Wine Industry Council during 2009.

Background knowledge from the findings of the project has been distributed to Riverland growers through regular messages produced as part of the CropWatch disease and pest management service provided by RWIDC throughout 2008/09 and 2009/2010.

A poster summarising this project was presented to the 17th Conference of the Australasian Plant Pathology Society at Newcastle in September 2009. A copy of this poster is presented below.

Reducing the Carbon Footprint in Riverland Vineyards: Assessing the efficacy and efficiency of control for powdery mildew by evaluating growers' spray diaries

PA Magarey [A], RW Emmett [B], TS Smythe [C], MM Moyer [D], JR Dixon [E], AJ Pietsch [F] and PM Burne [F]

[AG] South Australian R&D Institute, PO Box 411, Loxton, 5333, SA; [B] Dept of Primary Industries, Mildura, Vic, 3502; [C] Riverland Wine Industry Development Council, Berri, SA, 5343; [D] NYSAgExp Station, Geneva, NY, USA 14456; [E] SA Murray-Darling Basin Resource Information Centre, Berri SA 5343; [F] CCW Co-op. Ltd, Berri, SA, 5343.

[G] Correspondence details: Magarey Plant Pathology, pmagarey@riverland.net.au.

Introduction

- Riverland viticulture, near Loxton, South Australia (SA), comprises ~21,000 ha with ~1,200 growers.
- One spray using sulphur for control of powdery mildew (*Erysiphe necator*) costs the region ~$1.2 million.
- The SA winegrape industry seeks cheaper and environmentally improved disease management strategies.

Methods

- Spray records from 2006/07 were assessed for 1,200 Chardonnay, 1,450 Shiraz, and 13 Verdelho patches while 138 Chardonnay patches were examined in detail.
- Paper-based grower diary records of spray date, active ingredient and other details, were digitised and compared with winery pre-harvest assessments of mildew severity in each vineyard.
- A spray program evaluator:
  1) was devised in MS Access® using decision networks.
  2) compared diary records with a spray-schedule we had presumed to be optimum for control of *E. necator*.
  3) evaluated spray timing, treatment and technique in relation to temporally adjacent sprays; and
  4) calculated a disease management score for each diary record.

Findings

- Some growers controlled mildew well with 2-4 sprays.
- Others sprayed ≥ 12 times for poor control.
- Retrospectively, many sprays provided little benefit (Figure 1).

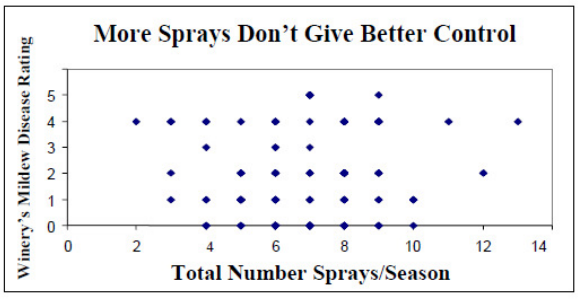


Figure 1: There was no correlation between number of sprays /season and pre-harvest disease score (ranked 1-5). Spray timing not spray number was critical.

- On average, 6-7 sprays were applied annually (range 2-14/season).
- 25% of growers applied ≥ 8 sprays/season.
- Of the total, 81% of vineyard area showed insignificant amounts of mildew at harvest. Only 3% ranked 5, with crop loss (Figure 3).
- Spatial analyses indicated clustering of vineyards with higher disease scores, suggesting disease control might be associated with cultural, sociological and/or meso-climatic factors including sources of inoculum.



Figure 2: Powdery mildew is the major reason sprays are applied in vineyards; its control is a major vineyard catalyst to the burning of dieseline and the production of carbon emissions.

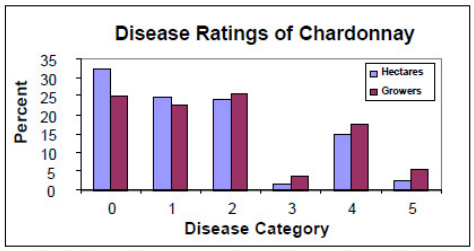


Figure 3: The disease rating for selected Riverland Chardonnay vineyards, indicating percent growers and hectares receiving the various mildew scores.

- Of note, higher incidence of mildew was associated with under-vine irrigation compared with drip irrigation.

Summary

The vineyard *spray program evaluator* can:

1) rapidly review spray diary records for other seasons or other regions.
2) develop industry bench-marks for fungicide use in the control of powdery mildew.
3) evaluate planned spray schedules for effectiveness and weakness before sprays are applied.
4) determine which spray schedules are effective and which are not; and
5) determine the minimum number of sprays for improved control of mildew, reduce fuel and chemical use, lower costs and reduce carbon emissions in Australian vineyards.

Conclusion

- **Improved spray programs with fewer sprays/season can be adopted for better control of powdery mildew in the Riverland.**
- **As few as 2-4 sprays/season may be adequate, allowing environmentally cleaner and lower cost mildew control.**

Riverland Wine Industry Development Council Inc.
State Government Victoria Department of Primary Industries
South Australian Research and Development Institute
Government of South Australia

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4. Scientific Report

Scientific details of the project are presented here as Appendix 1.

4.1. Introduction

In the Riverland each year, the viticulture sector spends significant time and effort controlling powdery mildew. Many vineyard managers apply 6-8 or more sprays to combat the disease yet some managers still fail in their pursuit to bring satisfactory control …further adding to the cost.

With the wine industry in recent years, falling on hard times there is considerable pressure to realise cost savings in production and, increasingly, additional pressure will be applied to reduce the emission of greenhouse gasses. At the same time there will be need to uphold the quality standards that have seen world-wide acceptance of our product. With this in mind, there was a real need to identify the scope for change of spraying less within the current regime for control of powdery mildew.

A desktop assessment of spray activity in 2007 was quite revealing. For instance, the application of one sulphur-based spray (at $50.00/ha) across the Riverland viticulture (comprising ~ 21,000 ha) cost around $1,050,000.

These figures assumed the following:

- Labour costs were fixed at $22/hour;
- Tractor speed was maintained at 6 km/hr;
- A single-row sprayer worked a vineyard with 3m row spacing and length 200m;
- Sulphur was charged at $52 for 25 kg applied at 400g/100L;
- Machinery cost (tractor and sprayer) were $20/hr;
- Fuel cost was $1.20/L with consumption at 18L/hr;
- Spray volume equated to 24L/100m or 800L/ha;
- Sprayer refill time took 15 minutes and refill volume was 2000L; and
- Turning time on the headland took 5 seconds.

If instead, a two-row spray machine were used across the 21,000 ha, the cost would be reduced to approximately $665,000 or $31.65/ha.

Environmental costs such as soil compaction, carbon emissions and potential disruption of ecosystem balance (mites etc.) are much harder to quantify but also return an expense to the triple bottom line. Due consideration of these figures very quickly illustrated that the cost of failure within powdery mildew controls alone was high and this did not factor in potential crop loss or opportunity cost.

Depending on disease pressure in any given year, across the population of winegrape growers in the Riverland there are varying degrees of success with control of powdery mildew. A relatively low, but unacceptably high number of growers each year suffer crop rejection because of low but unnecessarily high levels of disease. Clarification of reasons for this variation was considered helpful to improve the reliability and efficiency of control programs.

From a purely an economic point of view, the above figures gave indication of the potential for a targeted approach to the management of powdery mildew to reduce the reliance on spraying and instead, build a strategy for possible eradication of the disease within localities. An inbuilt safety net would be necessary and it is here that a disease calculator (forecaster) for powdery mildew and regional assessment offered great potential.

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For an advance in the effectiveness of controlling powdery to reduce input costs and potentially, the carbon footprint in Riverland viticulture, it was necessary to:

- assess current spray practices to see what was being done; and to
- assess planned control programmes before new strategies were implemented.

Records of past spray programmes existed. To meet food safety and quality assurance directives, over the last 5 to 10 years wineries have recognised the need for tighter control and reporting. A consequence was the collection of spray diary and vineyard disease assessment data. A challenge lay in extracting information from this massive pool of data and great opportunity lay in considering this in combination with recent advances in knowledge of powdery mildew development *eg* flag shoot appearance and the survival of inoculum reservoirs from season to season (Emmett et al, [1]).

In assessing then addressing apparent failures and successes in current spray programs, the Riverland viticulture sector was in a good position to develop a platform for the strategic management of powdery mildew inoculum. Work of this nature had the potential to provide tangible results for an industry under increasing demand for low (critical) input viticulture and sustainable management. Drought only acted to heighten the need for assistance in this. However, it was recognised that caution was needed to ensure that outputs were not skewed by management of extreme circumstances.

So, here's a summary of the project.

4.2. Project Overview

What we did

Spray diaries from specific vineyard patches for season 2006/07 were in paper-format. These were transposed to computer form so that individual records could be reviewed quickly. Each record in each diary needed assessment against a uniform standard by which they could be compared and to develop this, a theoretical, optimum spray strategy was defined. A computer-based system called the ***vineyard spray program evaluator***, was devised to facilitate rapid processing of the data. Full details are shown in Appendix 2.

We used the vineyard spray evaluator:

1) to compare each spray record in each spray diary in relation to the sprays applied both before and after that spray; and
2) to calculate a disease management score (DMScore) for each spray record.

The DMScore was calculated when each spray event was assessed and scored in relation to the three factors critical in determining the success of fungicide controls for powdery mildew (the so-called 3 T's). These are accuracy of spray Timing, the appropriateness of the choice of fungicide Treatment, and the effectiveness of the application Technique used.

The detail of the vineyard spray program evaluator is presented in Appendix 2.

The scores for each diary record were attributed for each spray event in relation to each of the above factors. The accumulated scores for each patch provided a simple but rapid means of comparing the diary entries for more than 1200 Chardonnay and 1450 Shiraz patches and for 13 of Verdelho, in the Riverland, South Australia. Given time constraints we made detailed evaluation of only a small sample of these records.

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What was accomplished

Analyses of these records showed that the ***vineyard spray program evaluator*** could rapidly calculate disease management scores from any computer-based diary of the same format and that it can be used in several ways:

1) to rapidly review past **records** of sprays applied in other seasons or other regions. From this, industry bench-marks for the use of fungicides to control powdery mildew can be devised for each region;
2) to evaluate next season's **planned** spray schedules for effectiveness and weakness before sprays are applied in the vineyard; and
3) to determine which spray schedules are effective and which are not.

From this, the minimum number of effective sprays needed to improve control of powdery mildew can be determined and as a result, the possibilities of reducing sprays, lowering costs, saving carbon credits and improving the level of control of powdery mildew in Riverland vineyards can be assessed. The ***vineyard spray program evaluator*** showed potential to be used elsewhere in Australian viticulture.

For instance, it could be developed for easy access by growers, vineyard managers, consultants and others as an online module on ***CropWatchOnline.com***.

4.3. Project Aim

The aims of the project were:

- **Analyse vineyard spray diaries and vineyard disease records** to assess spray programmes in relation to levels of disease control achieved;
- **Investigate control failures** (e.g. incorrect spray timing, fungicide rate/ha, product selection and range, poor spray coverage, varietal susceptibility etc.);
- **Assess the potential for a lower input spray regime** to achieve greater return per output;
- Communicate results through the Riverland's weekly CropWatch messages, other regional industry publications, and local media; and

Matters of particular interest were to:

- Develop an understanding of what drives good powdery mildew control;
- Determine what causes the failures; and
- Determine scope for change (disease control and financial performance)

4.4. Process

RWIDC overviewed the project undertaken by Peter Magarey, (formerly of SARDI, Loxton Research Centre), Dr Bob Emmett (Victorian DPI at Sunraysia) and Justin Dixon (South Australian Murray-Darling Basin Resource Information Centre (SAMRIC), Berri, SA). Peter Burne and Adam Pietsch from the CCW winery group and Alan Gilgen and Josh Nelson from Australian Vintage/McGuigan's Loxton Winery provided access to the spray diary information. Adam in particular provided excellent detailed assistance in obtaining spray diary data in digital format.

Spray Diaries

Detailed spray diaries from the Riverland winery co-operative, CCW, were the main source of information. The original aim had been to access data for a period of 5-6 years but when we assessed the winery records it became clear that they contained insufficient detail except for

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the last two seasons. And because all the records were only hand-written (in paper-based format) and the time constraints of a small project, it would have taken too long to copy each spray diary to computer form for us to use in the way we wanted. So, we only used data from one season, 2006/07 but this worked out well in the end because the database that Adam Pietsch transposed from paper to MS Excel™ spreadsheet on computer was big and it gave us good insight into what is current practice in terms of spraying strategies and operations.

Having installed the data to Excel™, we then transferred the data set to MS Access™ to allow more versatile and rapid assessments. The data base contained details from 1206 Chardonnay vineyard patches, 1468 Shiraz and 13 Verdelho.

To broaden the analyses of the project, additional spray-diaries from Australian Vintage were also accessed. Access to these records allowed extension to the demographic base of the spray records and increased the breadth of the assessment achieved.

The Database
The records for each patch in each cultivar comprised the number and date when sprays were applied, the brand name, concentration and rate of fungicide, insecticide and/or nutrient sprayed, and in what tank mixes with which products. To be sure grower confidentiality was honoured to a tee, details of vineyard numbers were only used to distinguish vineyard patches for each property, then ignored.

Given the enormity of the task of assessing all the data, we overviewed the records for the three cultivars and then concentrated only on cv. Chardonnay, investigating:

1) **All diaries** from vineyard patches **with at least some powdery mildew**; and
2) **Forty diaries** from vineyard patches **with no powdery mildew** at harvest.

We transposed the following **details of vineyard patches**:

- When sprays were applied (by date and **EL stage***);
- What sprays were applied (products used, rate/ha and other products in tank mix);
- How sprays were applied (volume of water/ha);
- How many sprays were applied (average and maximum spray intervals);
- Vine canopy design and irrigation type; and
- Powdery mildew vineyard patch disease ratings and when assessed. These assessments were recorded as part of CCW's annual pre-harvest review of crop quality and vineyard health for each patch.

* **EL stage** is a score assessed using the modified EL (Eichhorn-Lorenz) system to identify the growth stages of the grapevine (Pearce and Coombe 2004)[2]. We used the EL scores to set the following three **periods in the growing season**:

1) Bud burst (EL 4) to early flowering (EL 19);
2) Flowering (EL 20) to berries pea-size (EL 31); and
3) Beginning of bunch closure (EL 32) to end of leaf fall (EL 47).

[2] Pearce, I and Coombe, BG (2004) Grapevine Phenology, Ch 7 pp 150-166, in Dry, PR and Coombe, BG (Eds) Viticulture Volume 1 – Resources, Second Edition, Winetitles, Adelaide, SA. 255 pp.

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Then, for each vineyard patch and for each period in the season, we calculated:

- Total number of sprays applied;
- The timing of the sprays with respect to date and to EL growth stage;
- The interval between sprays (days);
- The number of products used for each application (# sprays/tank mix);
- The type of fungicide used and its concentration (active ingredient/100L),
- Total weight/volume for each product and season totals; and
- The spray volume used (L/ha).

This information gave us the capacity to make some prediction in the ability of individual sprays and of the complement used by each grower, to control mildew in that vineyard patch.

Timing, Treatment Technique - Scoring the Spray Records

To be consistent in assessing the factors important for good control of powdery mildew, we needed a rating system to evaluate the components of what Magarey et al 1994[3]; called the **three T's** of effective disease management: spray **timing**, the choice of spray **treatment** and the use of effective spray **technique**. To do this, we devised a system of scoring each spray record to allocate a 'disease management score' for each factor.
We evaluated each factor separately.

Disease Control Factor 1: Spray Timing

Setting a Standard Growing Season - Bio-fixing Spray Diary Records

When we began to review the diary records of spray timing it became clear that many EL scores were inconsistent; often growers had entered EL scores that did not match the spray dates they listed. For example, a spray in late December may have had an associated EL score listed at say EL 12. This indicated a growth period at which five leaves were separated, consistent with September, much earlier in the season than the date for which it was lodged.

We needed to do something about this confusion so that we could assess the records properly. Accordingly, we decided to simply ignore the EL records and define (bio-fix) a **standardised growing season** for cv. Chardonnay in which:

1) **Budburst** (EL 4 - 50% of leaf tips visible) occurred on 1st September (**Day 0**);
2) **Mid-flowering** (EL 19) occurred at **Week 8** from budburst; and
3) Flowers and berries were susceptible to powdery mildew from early flowering (EL 19) at **Week 8** to berries pea-size (EL 31) at **Week 13**.

We did the same for the other cultivars but bio-fixed different dates for budburst (Day 0), flowering (Week 8) and pea-size (Week 13).

For each vineyard, we assumed that:

- the growth stages (as above) of the same variety were uniform across all blocks in the Riverland; and that
- an epidemic of powdery mildew would begin at budburst (EL 4) with an unlimited supply of inoculum and increase progressively through the season.

[3] Magarey, P.A., Wachtel, M.F. and Emmett, R.W. (1994). Disease management - overview, pp 3-4, in *'Diseases and Pests'*, Vol. I. Grape Production Series, Nicholas, P.R., Magarey, P.A. and Wachtel, M.F. (Eds). Winetitles, Adelaide, South Australia. 106 pp. ISBN 1-875130-15-2.

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Setting a Standard Spray Season – Fixing a Disease Management Strategy
To assess the efficacy of disease control (the level of control) achieved by each spray event, we needed a standardised spray season to compare against. To do this, we supposed that a theoretical 'excellent disease management strategy' for each vineyard would:

- minimise the influence of initial inoculum (from budburst);
- inhibit the build-up of an epidemic in the vineyard patch;
- reduce the carry-over of inoculum to the following season; and
- ensure maximum control of powdery mildew at harvest (with a disease score of zero).

To convert this theory to practice, we set an effective spray-season for cv. Chardonnay to be from budburst (EL 4) to 31st December (EL 35). Epidemiological experience had shown that spraying later than this did not alter the disease score at harvest (Magarey and Emmett, pers. com.). We also know that if sprays are applied carefully and at the right times, powdery mildew can be controlled well and levels of overwintering inoculum reduced (Emmett et al 1994[4]). This allows a progressive reduction in number of sprays growers apply over successive seasons but the spray diaries gave us no way of knowing the background levels of inoculum in their vineyards.

So, in the circumstances, we fixed a theoretical optimum maximum disease management strategy requiring eight sprays fitted appropriately across a series of designated Spray Groups (Groups 0 – 3), as follows:

- **Spray Group 1: three early-season sprays**, to control primary inoculum from diseased buds/flagshoots and/or from cleistothecia/ascospores;
- **Spray Group 2: three post-flowering sprays**, to stop epidemic build-up; and
- **Spray Group 3: two sprays prior to harvest**, to make sure the fruit and foliage remained clean till harvest (see Table 1.1).

Setting Standard Spray Timing - Fixing Spray Dates
This above optimum spray strategy necessarily fixed optimum spray timings such that eight sprays were prescribed at the optimum spray timings of Weeks 2, 4, 6, 8, 10, 12-13, 14-15 and 16-17 from bud-burst (Table 1.1). This meant that, for instance, the optimum date of the first spray at Week 2 was set at 15th September; the second, two weeks later at Week 4 was on 29th September, and so on.

These standards were used as a basis to evaluate the diary records for spray timing.

Scoring Spray Timing (DMS STi) - Accommodating Variation
But before we could proceed, we needed to accommodate two sources of variation in the data. The first was variation between the actual spray dates and the designated eight optimum dates and the second was the variation in the need for precise spray timing as the season progresses. For good control of powdery mildew it is more critical to time sprays accurately early in the season than later so the significance of precision in spray dates for powdery control decreases with time.

In considering these variations, at least 31 combinations of spray timing during the growing season from EL4 to EL 35 were identified. To accommodate these in allocating a score for each spray record, a complex, systematic variable ranking was defined (see **Appendix 2**) for spray records in each Spray Sub-group. We allocated a different DMS STi depending on how close the sprays were applied to the optimum dates.

[4] Emmett, R.W., Magarey, P.A. and Magarey, R.D. (1994). Powdery mildew. pp 12-16 in *'Diseases and Pests'*, Vol. I. Grape Production Series, Nicholas, P.R., Magarey, P.A. and Wachtel, M.F. (Eds). Winetitles, South Australia. 106 pp.

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Here is a summary of how we judged accuracy:

- **accurate** sprays (with excellent timing) were applied within ± 3 days of the date of the recommended optimum spray timing;
- **less accurate** sprays (a little early or a little late) were applied between ±3 and ± 7 days of that date; and
- **inaccurate** sprays (too early or too late) were applied > 7 days before or after the designated target date.

Processing the Data – the Vineyard Spray Program Evaluator

To facilitate assessment of the spray diary database, a ***vineyard spray program evaluator*** that incorporated all the above assumptions, options and computations, was programmed in MS Access™, to undertake:

- comparison of spray timing against the standard spray schedule; and
- assessment of spray interval between the previous and next sprays; to give
- a **disease management score** for both spray timing and spray interval (**DMS STi**) for each spray in each patch.

To make the programming of the ***vineyard spray program evaluator*** easier, we constructed decision networks that illustrate the details in **Appendix 2** and represented the information for each spray condition at each growth stage (see **Appendix 3**). The networks show how the DMS STi were allocated for each disease and spray management option.

Decision networks have the advantage of presenting information in a form easily modified if a change is needed in the scoring system or in programming the computer-based vineyard spray program evaluator.

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Table 1.1: Allocation of Spray Groups and Sub-Groups According to a Recommended Spray Strategy against a Theoretical Epidemic of Grapevine Powdery Mildew in Vineyards of the Riverland, South Australia.

Spray Group	Option Timing of Sprays			Spray at Week # from Budburst
Group 0	**EL3 to EL4** (Woolly bud to Bud burst begins) for Chardonnay, EL 5 bud burst = 1st September			
Group 1	**EL5 to EL19** (Budburst to Flowering begins – 8 weeks)			
	EL Stage	**Optimum Spray Date**	**Range of Spray Dates**	
Sub-group 1.1	7 (First leaf separated)	15th September	12 Sept. - 18th Sept.	**2**
Sub-group 1.2	12 (5 leaves separated)	29th September	26th Sept. – 2nd Oct.	**4**
Sub-group 1.3	17 (12 leaves separated)	13th October	10th Oct. – 16th Oct.	**6**
Group 2	**EL20 to EL31** (10% caps off to Berries pea-size – 6 weeks)			
Sub-group 2.1	23 (50% caps off)	27th October	24th Oct. - 30th Oct.	**8**
Sub-group 2.2	27 (berry set; 2-3 mm)	10th November	7th Nov. – 13th Nov.	**10**
Sub-group 2.3	30-31 (berries 5-6 mm)	28th November	24th Nov. – 2nd Dec.	**12-13**
Group 3	**EL32 to EL35** (Bunch closure to Berries colour – 4 weeks)			
Sub-group 3.1	32 (bunch closure)	19th December	15th Dec. – 23rd Dec.	**15-16**
Sub-group 3.2	33 (Berries still hard)	9th January	5th Jan. – 13th Jan.	**18-19**

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How the System Works
The ***vineyard spray program evaluator*** processed the data base for cv Chardonnay. The evaluator used the Spray Scoring System of **Appendix 2** to give a disease management score, DMS STi, in relation to spray timing and spray interval for each spray record for each of the Spray Groups where:

DMScore STi = DMS STi Spray Group 1 + DMS STi Spray Group 2 + DMS STi Spray Group 3

Three examples show how this worked.

Example 1:

Suppose
Grower 1 in Patch 1 operated the optimum spray strategy and applied the recommended 'standard' sprays at excellent timing throughout the season. That is:

- In **Spray Group 1**, the 8-week period from budburst to beginning of flowering, **three sprays** were applied close to the target dates
  ie within ± 3 days of 15th September, 29th September and 13th October;
  and
- In **Spray Group 2**, the 6 week period from 10% caps off to berries pea-size, **three sprays** were applied close to the target dates
  ie within ± 3 days of 27th October, 10th November and 27th November;
  and
- In **Spray Group 3**, in the 4 week period from bunch closure begins to berries begin to colour, **two sprays** were applied close to the target dates
  ie within ± 3 days of 11th December and 25th December.

Then,
The ***spray evaluator*** assigned a disease management score (DMScore Spray Timing – DMS STi) as follows in Table 1.2:

Table 1.2. Spray Timing Score Card – Example 1

Spray Timing	DMScore
Spray Group:	DMS STi
1	1
2	1
3	1

So,
Patch 1 thus accumulated a Spray Timing Factor in that season,
DMScore STi = 1 + 1 + 1 = 3. ……Sub Total 1.

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Example 2:

In contrast, suppose
Grower 2 in Patch 2 began by applying the recommended spray with excellent timing but then encountered problems with his spray machine which was sidelined for several weeks so that:

- In **Spray Group 1**, the 8 week period from budburst to beginning of flowering, **one spray** was applied close to the target date
  ie within ± 3 days of 15th September,
  but that
- **both the next sprays were missed**,
  ie those due on 29th September and 13th October;
  and
- In **Spray Group 2**, the 6 week period from 10% caps off to berries pea-size, the **first two sprays** were a little late
  ie within ± 3-7 days of target dates 27th October and 10th November,
  and
- **the third spray** was well-timed
  ie within ± 3 days of 27th November;
  and
- In **Spray Group 3**, the 4 week period from bunch closure begins to berries begin to colour, the pump worked well and both sprays were well-timed!

Then,
From Table 1.1, the ***spray evaluator*** assigned a disease management score (DMScore Spray Timing – DMS STi) as follows in Table 1.3:

Table 1.3. Spray Timing Score Card – Example 2

Spray Timing	DMScore
Spray Group:	DMS STi
1	14
2	3.5
3	1

So,
Patch 2 thus accumulated a Spray Timing Factor in that season,
DMScore STi = 14 + 3.5 + 1 = 18.5. ……Sub Total 2.

Example 3:

Suppose
Grower 3 in Patch 3 suffered a major setback in the drought and decided to moth ball his vines and not to apply any sprays for powdery mildew, so that

- In **Spray Group 1**, there was **no spray**;
  and
- In **Spray Group 2**, there was **no spra**y;
  and
- In **Spray Group 3**, there was **no spray**

Then,
From Table 1.1, the ***spray evaluator*** assigned a disease management score (DMScore Spray Timing – DMS STi) as follows in Table 1.4:

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Table 1.4. Spray Timing Score Card – Example 3

Spray Timing	DMScore
Spray Group:	DMS STi
1	20
2	18
3	7

So,
Patch 3 thus accumulated a Spray Timing Factor in that season,
DMScore STi = 20 + 18 + 7 = 45. ……Sub Total 3.

_____

These Disease Management Scores for the Spray Timing Factor (DMS STi) for each patch allowed us to evaluate the influence of spray timing and spray interval for that cultivar on the subsequent levels of powdery mildew where:

The lower the DMScore Spray Timing, the better the expected outcomes.

In summary, Grower 1 in Patch 1 with a DMS Ti = 3, did a good job with spray timing and all things being equal, would have delivered high quality (powdery mildew free) fruit to the winery. Grower 2 in Patch 2, scoring 18.5, recovered well from a poor start but the broken spray pump at a critical time cost significantly in effectively managing the powdery mildew epidemic. Fruit in that patch was at risk of being rejected at harvest. Grower 3 in Patch 3, in scoring 45, for obvious reasons, failed to control the mildew. The likely result was an uncontrolled epidemic of mildew in that patch with the severe consequence of the fruit being rejected at the winery.

Disease Control Factor 2: Spray Treatment

To develop a Disease Management Score for Spray Treatment (DMScore STr), the two components of this factor in the control of powdery mildew *ie* fungicide type and rate, were assessed separately where:

DMScore STr = DMS FT + DMS FR, as defined below.

Fungicide Type (DMS FT)
All fungicides registered for the control of powdery were rated equally for managing the disease and were given the best (lowest) possible Disease Management Score for Fungicide Type (DMS FT). All others products were given a high score as below (Table 2.1).

Table 2.1. Spray Treatment Fungicide Type

Fungicide Type	
Registered for powdery mildew	DMScore (DMS FT)
Yes	1
No	10

Fungicide Rate (DMS FR)
Two classifications of registered fungicides were recognised:
1) Sulphur based products; and
2) Others.

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Different rates of sulphur have different levels of efficacy in controlling powdery mildew. Experience shows that good control is achieved by rates in excess of 300 g ai/100L tank mix but that a rate of more than 600 g ai/100L is best. A Disease Management Score for Fungicide Rate (DMS FR) allocated as below (Table 2.2), reflected this.

Table 2.2. Spray Treatment Fungicide Rate

Fungicide Rate	
Concentration chemical (g ai/100L)	**DMScore (DMS FR)**
Sulphur	
≥ 600	1
300-599	3
200-299	7
< 200	10
Other Products	
≥ Label Rate	1
< Label Rate	10

How the System Works
As for the Spray Timing factor, we used the ***vineyard spray program evaluator*** to assess the data base but with the Spray Scoring System for Spray Treatment. This gave a disease management score, DMScore Spray Treatment (DMS STr), for each spray record, accumulating a score for each patch.

Two examples show how this worked.

Example 1
Suppose
Grower 1 in Patch 1 (as above), used Sulphur as a registered fungicide for powdery mildew at the recommended maximum rate of 600 g ai/100L:

Then,
The ***spray evaluator*** assigned a DMScore Spray Treatment (DMS STr) for Patch 1, accumulating a DMS STr as below:

DMScore STr for Fungicide Type + Fungicide Rate
= DMS FT + DMS FR
= 1 + 1 = 2.

So,
Patch 1 thus accumulated a Spray Treatment Factor in that season,
DMScore STr = 2. ……Sub Total 4.

Example 2
Suppose
Grower 2 in Patch 2 (as above), also used Sulphur but at the less than useful low rate of < 200 g ai/100L:

Then,
The ***spray evaluator*** assigned a disease management score (DMScore Spray Treatment–DMS STr) for Patch 2 accumulating a DMS STr as below:

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DMScore STr for Fungicide Type + Fungicide Rate
= DMS FT + DMS FR
= 1 + 10 = 11.

So,
Patch 2 thus accumulated a Spray Treatment Factor in that season,
DMScore STr = 11. ……Sub Total 5.

_____

These Disease Management Scores for the Spray Treatment Factor (DMS STr) for each patch allowed us to evaluate the influence of fungicide type and fungicide rate for that cultivar on the subsequent levels of powdery mildew where:

The lower the DMScore Spray Treatment, the better the expected outcomes.

In summary, Patch 1 was well managed and we expected a good outcome in terms of a high level of efficacy of control achieved by the sprays that were applied. In contrast, the spray treatments applied to Patch 2 were identified as deficient in terms of Fungicide Rate and this might have led to unacceptably high levels of disease at harvest.

Disease Control Factor 3: Spray Technique

To develop a Disease Management Score for Spray Technique (DMScore STe), the two components of this factor in the control of powdery mildew *ie* spray volume and spray tank mixes, were assessed separately where

DMScore STe = DMS SV + DMS SM, as defined below.

Spray Volume (DMS SV)
Because powdery mildew spreads persistently and grows superficially on green parts of the vine, when spraying, a high level of fungicide coverage is critical to effective control. To achieve a good coating of fungicide on the foliage, an increase in the volume of spray through a season is needed in proportion to the increase in volume of the vine canopy.

The table below (Table 3.1) outlines the way we set the required volume of spray (L/ha) and the associated Disease Management Score Spray Volume (DMS SV) for each step in the growing season, that is, for each of Spray Groups 1-3 listed in Table 1.1.

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Table 3.1. Spray Technique Spray Volume

Spray Volume		
Volume water applied		DMScore (DMS SV)
Spray Group 1	(L/ha))	
1.1	≥ 400	1
1.1	< 400	10
1.2	≥ 600	1
1.2	< 600	10
1.3	≥ 800	1
1.3	< 800	10
Spray Group 2		
2	≥1000	1
2	< 1000	10
Spray Group 3		
3	≥ 1000	1
3	< 1000	10

Spray Mix (DMS SM)
When spraying for effective disease control, it is unwise to mix too many products in a spray tank. Problems from incompatibility of tank mixed products compound with an increase in the number mixed. To evaluate the influence of this component in effective disease control, we set the Disease Management Score Spray Mix (DMS SM) as below (Table 3.2):

Table 3.2. Spray Technique Spray Mix

Spray Mix	
Number of products (# products/tank mix)	DMScore (DMS SM)
0 - 3	1
4 - 5	3
>5	10

How the System Works
Two examples show how the ***vineyard spray program evaluator*** assessed the data base to give a disease management score, DMScore Spray Technique (DMS STe), for each spray record, accumulating a score for each patch.

Example 1
Suppose
Grower 1 in Patch 1 (as above), sprayed a registered fungicide for powdery mildew in Spray Sub-group 1.2 at the rate of 600 gm/100L recommended for that time but not mixed with any other product:

Then,
The ***spray evaluator*** assigned a disease management score (DMScore Spray Technique – DMS STe) for Patch 1 as below:

DMScore STe = DMS SV + DMS SM
= 1 + 1 = 2.

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So,
Patch 1 thus accumulated a Spray Technique Factor in that season,
DMScore STe = 2. ……Sub Total 6.

Example 2
Suppose
Grower 2 sprayed another patch (Patch 2 from above) in Spray Group 2 with the same registered fungicide as Grower 1 but at the low rate of 200 gm/100L and this was mixed with two products for downy mildew and three nutrient sprays – a general nutrient product, one with Magnesium and one for Zinc:

Then,
The ***spray evaluator*** assigned a disease management score (DMScore Spray Technique – DMS STe) for this patch as below:

DMScore STe = DMS SV + DMS SM = 10 + 10 = 20.

So,
Patch 2 thus accumulated a Spray Technique Factor in that season,
DMScore STe = 20. ……Sub Total 7.

These Disease Management Scores for the Spray Technique Factor (DMS STe) for each patch allow us to evaluate the influence of spray volume and spray mix for that cultivar on the subsequent levels of powdery mildew where:

The lower the DMScore Spray Treatment, the better the expected outcomes.

In summary, Patch 1 with a low DMS Ste, was likely to have had a good outcome in managing the mildew epidemic there – at least as far as applying an appropriate spray volume to wet the canopy with a suitable tank mix. All things being equal, it is expected that the patch would have delivered high quality (powdery mildew free) fruit to the winery. In Patch 2, a high score resulted from an inadequate spray volume in a tank mix that was very likely ineffective and is likely to have been ineffective in managing the powdery mildew epidemic there. Fruit in that patch was at risk of being rejected at harvest.

We used the ***vineyard spray program evaluator*** to evaluate the data base for each spray entry to calculate spray dose for each treatment applied where:

Spray Dose	=	concentration of chemical	x	spray volume
(Rate of product/ha)		(Rate of product/100L)		(Litres of water/ha).

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4.5. Outcomes

Number of sprays

The project showed that some growers achieved excellent control with as few as 2-4 applications while others achieved poor control having sprayed 12 or more times. Many growers sprayed frequently with little benefit. Consequently, the evidence pointed toward there being considerable scope for the industry to make savings in managing the disease with fewer sprays.

For instance, while Chardonnay growers applied an average of 6-7 sprays (range 2-13)/season, 25% of the patches were sprayed eight or more times. Despite this, most growers (73% of the patches, accounting for 81% of total area surveyed) applied less than this but had insignificant amounts of mildew in their vineyard patch at pre-harvest. This suggested that the additional sprays applied by the 25% of growers, were unwarranted.

The good news is that only a few patches (6% in number accounting for 3% of the area) had levels of disease sufficient for the winery to reject the crop. This means that most growers did an acceptable job in controlling the disease, even though the outcome might have been achieved with fewer sprays.

Some growers applied five or fewer sprays yet achieved the same high level of control as those who sprayed many more times. Figure 6 shows the number sprays applied for powdery mildew/patch/season for cv. Chardonnay during 2006/07.

Let's look at the detail this shows. If we take the points where there was no disease at the pre-harvest assessment, that is, the points on the graph with a Disease Rating of zero, we see this occurred where growers applied between 4 and 10 sprays. This raises the question: if some growers achieved excellent control with four sprays, did others need to apply 10 for the same outcome?

At the other end of the scale, if we take the points with high disease scores, with a rating of say 4 or 5, this occurred in patches sprayed as few as two times and in patches sprayed as many as 13 times. We could perhaps reason that two sprays were not enough to achieve good control but why did some growers fail to achieve excellent control with as many as 13 sprays?

Overall, Figure 6 shows no link between the number of sprays applied and the level of disease control achieved. This means that more sprays was not better. On average, no better control of powdery was achieved by the application of more sprays.

Growers who applied 4-5 sprays generally achieved as effective control as did those who applied 10-13 times. The probable explanation is that it was not the number of fungicides but their timing and/or coverage that was critical in controlling powdery mildew.

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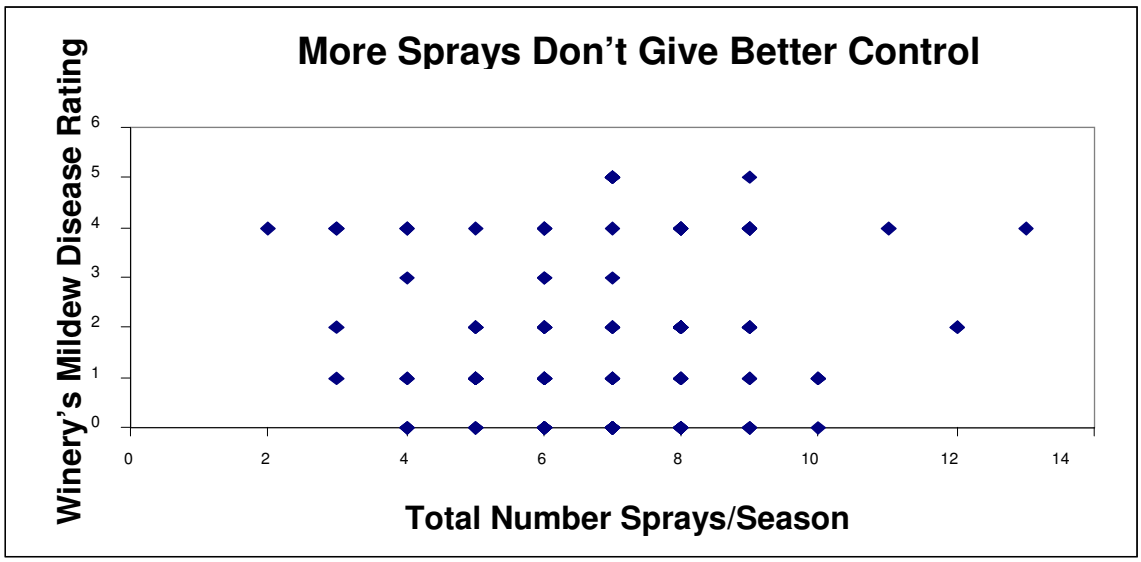


Figure 6. Plot of the number sprays applied for powdery mildew/patch for cv. Chardonnay, 2006/07, showing that better control of powdery was not achieved when more sprays were applied.

The three T's of spraying

Timing

A comparison of the disease management scores (DMScore) from the vineyard spray program evaluator, with the theoretical optimum spray strategy (Appendix 2) showed near 45% of growers applied well-timed programs whereas 55% comprised poorly timed sprays.

To check this in yet more detail, a Spray Timing Rating was developed to assess the date of each spray record within each spray diary. A scale of 1-20 was established, founded on the knowledge of powdery mildew epidemiology (how the disease spreads across a vineyard during a season) and of the susceptibility of vines to powdery mildew (Figure 7). From this, a theoretical 'best timing' strategy of spraying was developed. A patch with a score of less than 6 was considered to have very good spray timing, and a patch with 1 to 3, excellent timing. To the contrary, patches with very poorly timed sprays, often missing key target windows for powdery mildew's development, was given a score of 10 or more.

The detail of this is explained in Appendix 2.

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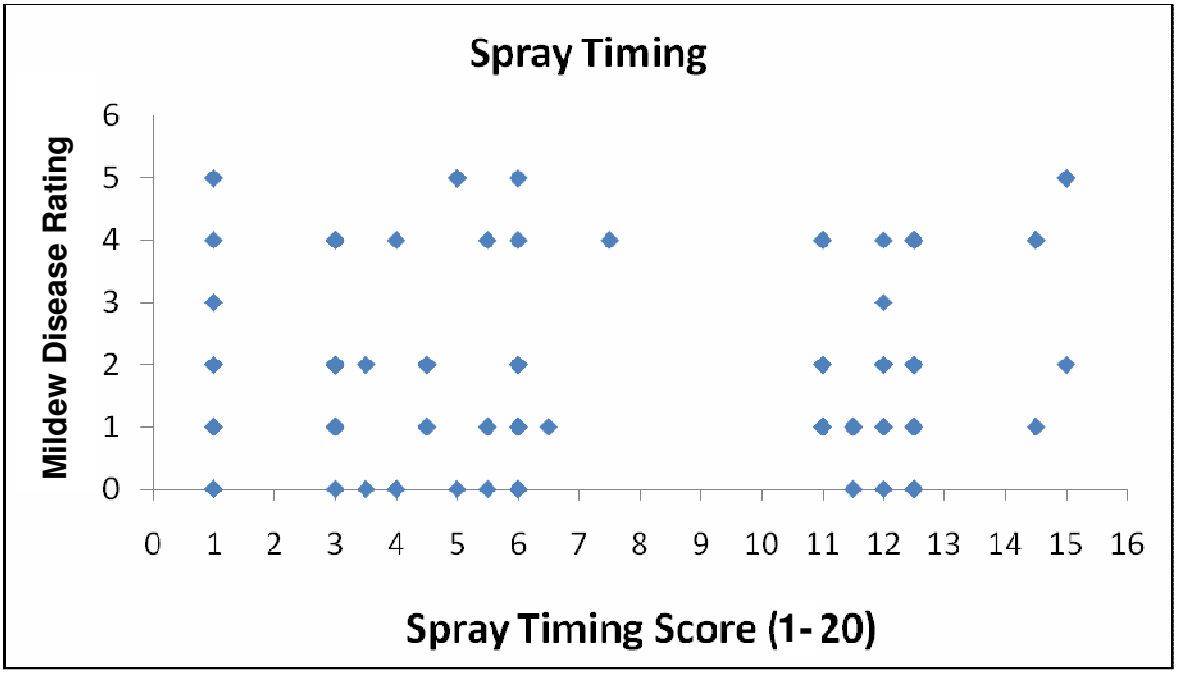


Figure 7- Summary of Spray Timing scores and associated Disease Ratings. See Appendix 1 for details.

Treatment
Nearly all growers chose the right products – that is, most growers used products registered effective against powdery mildew and relatively few combined more than two or three products, not risking incompatibility from poor tank mixes.

Technique
Because the spray diaries lacked data on sprayer calibration it was not possible to properly assess the efficiency of spray coverage. This prevented accurate assessment of spray technique as a factor in disease control. Similarly, the absence of records of the amount of disease in vineyards from the previous season (ie inoculum reservoirs) prevented determination of the efficacy of sprays (ie how effective were they?).

Spatial analyses
Analyses of the geographical spread of disease scores for each patch showed that there was a distinctive clustering of vineyards with higher disease scores. Perhaps this occurred where closely adjacent patches with susceptible varieties had high levels of disease last season, making disease control more difficult in that locality in the season of study. Perhaps too, there was some local microclimatic factor that made disease control difficult in that locality. Equally, the clustering of highly diseased patches might indicate the influence of some cultural or sociological factor. For instance, neighbouring growers might have tried the same inefficient spray strategy without success.

The result is that disease control in these localities might be improved by addressing cultural, sociological and/or meso-climatic factors.

Cultural practices
Of significant note, higher incidences of powdery mildew occurred in patches with under-vine irrigation as compared with drip irrigation. In a study of 1206 patches of Chardonnay (Figure 8) and 1468 of Shiraz (data not shown), there were some interesting data: powdery was of a

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higher incidence in patches with **undervine sprinklers** (UVS) much more often than in **drip** or **overhead sprinkler** (OHS) irrigated patches.

		DRIP	UVS	OHS	FRW	UNKNOWN	Total
ALL	#	397	412	321	41	35	***1206***
	%	33	34	27	3	3	*100*
Winery Mildew Disease Rating							
0	#	384	357	295	38	35	*1109*
	%	35	32	27	3	3	*100*
1	#	4	19	6			*29*
	%	14	66	21	0	0	*100*
2	#	6	13	15	1		*35*
	%	17	37	43	3	0	*100*
3	#	2	1				*3*
	%	67	33	0	0	0	*100*
4	#	1	16	3	2		*22*
	%	**5**	**73**	**14**	9	0	*100*
5	#		6	2			*8*
	%	**0**	**75**	**25**	0	0	*100*
						Total # of patches	*1206*

Figure 8- Summary of winery assessed powdery mildew scores and associated number of patches with different irrigation methods in Riverland cv Chardonnay vineyards 2006/07.

A similar though less obvious trend appeared the data from Shiraz vineyards (data not shown).

One reason that may account for these observations is that the undervine sprinklers are likely to raise vineyard hence canopy relative humidity more than drip irrigation systems. At higher humidity (>40-60%RH), powdery mildew produces more spores and thus multiplies and spreads more quickly.

4.6. Conclusions

- Some growers controlled mildew well with 2-4 sprays.
- Others sprayed ≥ 12 times for poor control.
- Retrospectively, many sprays provided little benefit
- On average, 6-7 sprays were applied annually (range 2-14/season).
- 25% of growers applied ≥ 8 sprays/season.
- Of the total, 81% of vineyard area showed insignificant amounts of mildew at harvest. Only 3% ranked 5, with crop loss (Figure 3).
- Spatial analyses indicated clustering of vineyards with higher disease scores, suggesting disease control might be associated with cultural, sociological and/or meso-climatic factors including sources of inoculum.
- Of note, higher incidence of mildew was associated with under-vine irrigation compared with drip irrigation.

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- A vineyard *spray program evaluator* can:
  - 1) rapidly review spray diary records for other seasons or other regions.
  - 2) develop industry bench-marks for fungicide use in the control of powdery mildew.
  - 3) evaluate planned spray schedules for effectiveness and weakness before sprays are applied.
  - 4) determine which spray schedules are effective and which are not; and
  - 5) determine the minimum number of sprays for improved control of mildew, reduce fuel and chemical use, lower costs and reduce carbon emissions in Australian vineyards.
- Improved spray programs with fewer sprays/season can be adopted for better control of powdery mildew in the Riverland.
- As few as 2-4 sprays/season may be adequate, allowing environmentally cleaner and lower cost mildew control

Appendix 2: Spray Timing Scores for an Optimum Powdery Mildew Spray Schedule, Riverland, SA

Appendix 2: Spray Option Conditions and Disease Management Scores for Spray Timing and Interval, for an Optimum Fungicide Management Strategy for Grapevine Powdery Mildew in Vineyards of the Riverland, South Australia.

Spray Schedule Action		Options re Timing	DMScore Spray Timing
Spray Group 1			
Apply three sprays		Note: Apply the conditions "… within ± 4-6(7) days of target" and "… > 6(7) days too early or too late" up to and including Spray Group 2.2.3; for Groups 2.3.1 to 3.3.3, apply the condition "…within ± 5-10 days of target" and "…> 10 days too early or too late" instead.	
1.	Apply **three** sprays with **excellent timing**	Three sprays are excellently timed (applied within ± 3 days of target).	**1**
2.	Apply **three** sprays but **one spray is a little early or a little late**.	Two sprays are excellently timed and either 1, **2 or 3** where: 1 = the first spray is applied ± 4-6(7) days of target; or	**4**
		2 = the second spray is within ± 4-6(7) days of target; or	**3.5**
		3 = the third spray is within ± 4-6(7) days of target.	**3**
3.	Apply **three** sprays but **two sprays are a little early or a little late**.	One spray is excellently timed and either 1, 2 or 3 where: 1 = the first and second sprays are within ± 4-6(7) days of target; or	**5.5**
		2 = the first and third sprays are within ± 4-6(7) days of target; or	**5**
		3 = the second and third sprays are within ± 4-6(7) days of target.	**4.5**
4.	Apply **three** sprays but **all are a little early or a little late**.	No spray is excellently timed and all are applied within ± 4-6(7) days of target.	**6**
5.	Apply **three** sprays but **one spray is too early or too late** (ie is missed) [just better than applying 2 sprays with excellent timing].	Two sprays are excellently timed and either 1, 2 or 3 where: 1 = the first spray is applied > 6(7) days too early or too late (ie effectively is missed) and is applied in sub-group 1.2 or 1.3 instead and the second and third sprays well-timed; or	**7.5**
		2 = the second is missed and is applied in adjacent sub-groups 1.1 or 1.3 instead and the first and third are well-timed; or	**7**
		3 = the third is missed and applied in 1.1 or 1.2 instead and the first and second sprays are well-timed.	**6.5**
6.	Apply **three** sprays but **two sprays are too early or too late** (ie are missed) [just better than applying 1 spray with excellent timing].	One spray is excellently timed and either 1, 2 or 3 where: 1 = the first and second sprays are applied > 6(7) days too early or too late (ie effectively are missed) and are applied in sub-group 1.3 instead and the third spray is well-timed; or	**9**
		2 = the first and third are missed and are applied in sub-group 1.2 instead and the second spray is well-timed; or	**8.5**
		3 = the second and third sprays are missed and applied in 1.1 instead and the first spay is well-timed.	**8**

Appendix 2: Spray Timing Scores for an Optimum Powdery Mildew Spray Schedule, Riverland, SA

Spray Schedule Action		Options re Timing	DMScore Spray Timing
Apply two sprays		Note: Apply the conditions "… within ± 4-6(7) days of target" and "… > 6(7) days too early or too late" up to and including Spray Group 2.2.3; for Groups 2.3.1 to 3.3.3, apply the condition "…within ± 5-10 days of target" and "…> 10 days too early or too late" instead.	
7.	Apply **two sprays** with **excellent timing** (ie one spray is missed)	Two sprays are excellently timed and either 1, 2 or 3 where: 1 = the first spray is missed; or	**12.5**
		2 = the second is missed; or	**12**
		3 = the third is missed.	**11.5**
8.	Apply **two sprays** but **one is a little early or late.**	One spray is excellently timed and 1, 2 or 3 where: 1 = the sprays are applied in sub-groups 1.2 and 1.3 and the spray within 1.2 is within ± 4-6(7) days of target; or	**13.5**
		1a = the sprays are applied in sub-groups 1.2 and 1.3 and the spray within 1.3 is within ± 4-6(7) days of target; or	**13**
		2 = the sprays are applied in sub-groups 1.1 and 1.3 and the spray within 1.1 is within ± 4-6(7) days of target; or	**12.5**
		2a = the sprays are applied in sub-groups 1.1 and 1.3 and the spray within 1.3 is within ± 4-6(7) days of target; or	**12**
		3 = the sprays are applied in sub-groups 1.1 and 1.2 and the spray within 1.1 is within ± 4-6(7) days of target; or.	**11.5**
		3a = the sprays are applied in sub-groups 1.1 and 1.2 and the spray within 1.2 is within ± 4-6(7) days of target.	**11**
9.	Apply **two sprays** but **one is early or late** (ie is missed) [nearly equates 1 spray with excellent timing].	One spray is excellently timed and the second is applied > 6(7) days too early or too late ie effectively is missed, and 1, 2 or 3 where: 1 = the first and second spray are applied in sub-group 1.3; or 1a = the first is applied in sub-group 1.3 and the second in 1.2 or 1b = the first is applied in sub-group 1.3 and the second in 1.1 or	**13.5** **12.5** **12**
		2 = the first and second spray are applied in sub-group 1.2; or 2a = the first is applied in sub-group 1.2 and the second in 1.3 or 2b = the first is applied in sub-group 1.2 and the second in 1.1 or	**13** **12.5** **11.5**
		3 = the first and second spray are applied in sub-group 1.1; or 3a = the first is applied in sub-group 1.1 and the second in 1.3 or 3b = the first is applied in sub-group 1.1 .and the second in 1.2	**12.5** **12** **11**
10.	Apply **one spray** with **excellent timing** (ie two sprays are missed).	One spray is excellently timed and 1, 2 or 3 where: 1 = the spray is applied in sub-group 1.3; or	**15**
		2 = the spray is applied in sub-group 1.2; or	**14.5**
		3 = the spray is applied in sub-group 1.1.	**14**
11.	Apply **no sprays** (three sprays are missed)	No sprays in any sub-groups 1.1, 1.2 or 1.3	**20**

Appendix 2: Spray Timing Scores for an Optimum Powdery Mildew Spray Schedule, Riverland, SA

Spray Schedule Action		Options re Timing	DMScore Spray Timing
Spray Group 2			
Apply three sprays		Note: Apply the conditions "… within ± 4-6(7) days of target" and "… > 6(7) days too early or too late" up to and including Spray Group 2.2.3; for Groups 2.3.1 to 3.3.3, apply the condition "…within ± 5-10 days of target" and "…> 10 days too early or too late" instead.	
12.	Apply **three** sprays with **excellent timing**	Three sprays are excellently timed (applied within ± 3(4) days of target).	**1**
13.	Apply **three** sprays but **one spray is a little early or a little late**.	Two sprays are excellently timed and either 1, 2 or 3 where: 1 = the first spray is applied ± 4-6(7) days of target; or	**2**
		2 = the second spray is within ± 4-6(7) days of target; or	**1.5**
		3 = the third spray is within ± 4-6(7) days of target.	**1**
14.	Apply **three** sprays but **two sprays are a little early or a little late**.	One spray is excellently timed and either 1, 2 or 3 where: 1 = the first and second sprays are within ± 4-6(7) days of target; or	**3.5**
		2 = the first and third sprays are within ± 4-6(7) days of target; or	**3**
		3 = the second and third sprays are within ± 4-6(7) days of target.	**2.5**
15.	Apply **three** sprays but **all are a little early or a little late**.	No spray is excellently timed and all are applied within ± 4-6(7) days of target.	**4**
16.	Apply **three** sprays but **one spray is too early or too late** (ie is missed) [just better than applying 2 sprays with excellent timing].	Two sprays are excellently timed and either 1, 2 or 3 where: 1 = the first spray is applied > 6(7) days too early or too late ie effectively is missed, and is applied in sub-group 2.2 or 2.3 instead and the second and third sprays well-timed; or	**5.5**
		2 = the second is missed and is applied in adjacent sub-groups 2.1 or 2.3 instead and the first and third are well-timed and; or	**5**
		3 = the third is missed and applied in 2.1 or 2.2 instead first and the first and second sprays are good.	**4.5**
17.	Apply **three** sprays but **two sprays are too early or too late** (ie are missed) [just better than applying 1 spray with excellent timing].	One spray is excellently timed and either 1, 2 or 3 where: 1 = the first and second sprays are applied > 6(7) days too early or too late ie effectively are missed and are applied in sub-group 2.3 instead and the third spray is well-timed; or	**7**
		2 = the first and third are missed and are applied in sub-group 2.2 instead and the second spray is well-timed; or	**6.5**
		3 = the second and third sprays are missed and applied in 2.1 instead and the first spay is well-timed.	**6**

Appendix 2: Spray Timing Scores for an Optimum Powdery Mildew Spray Schedule, Riverland, SA

Spray Schedule Action		Options re Timing	DMScore Spray Timing
Apply two sprays		Note: Apply the conditions "… within ± 4-6(7) days of target" and "… > 6(7) days too early or too late" up to and including Spray Group 2.2.3; for Groups 2.3.1 to 3.3.3, apply the condition "…within ± 5-10 days of target" and "…> 10 days too early or too late" instead.	
18.	Apply **two sprays** with **excellent timing** (ie one spray is missed)	Two sprays are excellently timed and either 1, 2 or 3 where: 1 = the first spray is missed; or	**10.5**
		2 = the second is missed; or	**10**
		3 = the third is missed.	**9.5**
19.	Apply **two sprays** but **one is a little early or late.**	One spray is excellently timed and 1, 2 or 3 where: 1 = the sprays are applied in sub-groups 2.2 and 2.3 and the spray within 2.2 is within ± 4-6(7) days of target; or	**11.5**
		1a = the sprays are applied in sub-groups 2.2 and 2.3 and the spray within 2.3 is within ± 4-6(7) days of target; or	**11**
		2 = the sprays are applied in sub-groups 2.1 and 2.3 and the spray within 2.1 is within ± 4-6(7) days of target; or	**10.5**
		2a = the sprays are applied in sub-groups 2.1 and 2.3 and the spray within 2.3 is within ± 4-6(7) days of target; or	**10**
		3 = the sprays are applied in sub-groups 2.1 and 2.2 and the spray within 2.1 is within ± 4-6(7) days of target; or.	**9.5**
		3a = the sprays are applied in sub-groups 2.1 and 2.2 and the spray within 2.2 is within ± 4-6(7) days of target.	**9**
20.	Apply **two sprays** but **one is early or late** (ie is missed) [nearly equates 1 spray with excellent timing].	One spray is excellently timed and the second is applied > 6(7) days too early or too late ie effectively is missed, and 1, 2 or 3 where: 1 = the first and second spray are applied in sub-group 2.3; or 1a = the first is applied in sub-group 2.3 and the second in 2.2 or 1b = the first is applied in sub-group 2.3 and the second in 2.1 or	**11.5** **10.5** **10**
		2 = the first and second spray are applied in sub-group 2.2; or 2a = the first is applied in sub-group 2.2 and the second in 2.3 or 2b = the first is applied in sub-group 2.2 and the second in 2.1 or	**11** **10.5** **9.5**
		3 = the first and second spray are applied in sub-group 2.1; or 3a = the first is applied in sub-group 2.1 and the second in 2.3 or 3b = the first is applied in sub-group 2.1 .and the second in 2.2	**10.5** **10** **9**
Apply one spray			
21.	Apply **one spray** with **excellent timing** (ie two sprays are missed).	One spray is excellently timed and 1, 2 or 3 where: 1 = the spray is applied in sub-group 2.3; or	**13**
		2 = the spray is applied in sub-group 2.2; or	**12.5**
		3 = the spray is applied in sub-group 2.1.	**12**
22.	Apply **no sprays** (three sprays are missed)	No sprays in any sub-groups 2.1, 2.2 or 2.3	**18**

Appendix 2: Spray Timing Scores for an Optimum Powdery Mildew Spray Schedule, Riverland, SA

Spray Schedule Action		Options re Timing	DMScore Spray Timing
Spray Group 3			
Apply two sprays			
23.	Apply **two** sprays with **excellent timing**	Two sprays are excellently timed (applied within ± 4 days of target).	**1**
24.	Apply **two** sprays but **one is a little early or a little late**.	One spray is excellently timed and either 1 or 2 where: 1 = the first spray is applied ± 5-10 days of target; or	**1.5**
		2 = the second spray is within ± 5-10 days of target	**1**
25.	Apply **two** sprays but **both are a little early or a little late**.	Both sprays are applied within ± 5-10 days of target.	**1.5**
26.	Apply **two** sprays but **one is too early or too late** (ie is missed) [just better than applying one spray with excellent timing].	One spray is excellently timed and either 1 or 2 where: 1 = the first spray is applied > 6(7) days too early or too late ie effectively is missed, and is applied in sub-group 3.2 instead; or	**2**
		2 = the second is missed and is applied in sub-group 3.1 instead.	**2**
27.	Apply **two** sprays but **both are too early or too late** (ie are missed) [just better than applying one spray with poor timing].	One spray is excellently timed and either 1 or 2 where: 1 = the first spray is are applied > 6(7) days too early or too late ie effectively is missed and is applied in sub-group 3.2 instead; or	**2**
		2 = the second is missed and is applied in sub-group 3.1 instead.	**2**
Apply one spray			
28.	Apply **one spray** with **excellent timing** (ie one spray is missed).	One spray is excellently timed and 1 or 2 where: 1 = the spray is applied in sub-group 3.2; or	**4**
		2 = the spray is applied in sub-group 3.1.	**3.5**
29.	Apply **one spray a little early or a little late** (ie one spray is missed).	One spray is applied within ± 5-10 days of target; and 1 or 2 where: 1 = the spray is applied in sub-group 3.2 within ± 5-10 days of target; or	**4**
		2 = the spray is applied in sub-group 3.1 within ± 5-10 days of target.	**3.5**
30.	Apply **one spray too early or a too late** (ie one spray is missed).	One spray is applied > 6(7) days of target and 1 or 2 where: 1 = the spray is applied in sub-group 3.2 instead; or	**4**
		2 = the spray is applied in sub-group 3.1 instead; or	**3.5**
31.	Apply **no sprays** (two sprays are missed)	No sprays in any sub-groups 3.1 or 3.2	**7**

Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

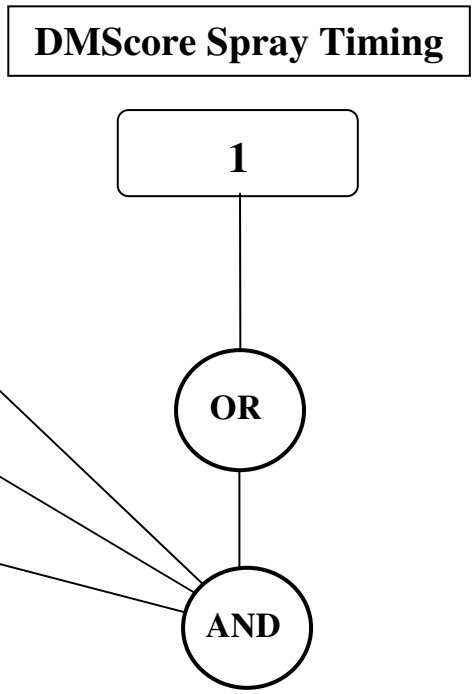
Appendix 3: Decision Networks for an Optimum Spray Schedule and Disease Management Scores for Timing Powdery Mildew Sprays

The network diagrams are presented here only for Spray Group 1.

Spray Group 1: Diagram 1

1. Apply three sprays with excellent timing

Spray Group	Spray Sub-Group	
1.1	1.1.1	
	1.1.2	
	1.1.3	
1.2	1.2.1	
	1.2.2	
	1.2.3	
1.3	1.3.1	
	1.3.2	
	1.3.3	
2.1	2.1.1	
	2.1.2	
	2.1.3	
2.2	2.2.1	
	2.2.2	
	2.2.3	
2.3	2.3.1	
	2.3.2	
	2.3.3	
3.1	3.1.1	
	3.1.2	
	3.1.3	
3.2	3.2.1	
	3.2.2	
	3.2.3	



Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

Spray Group 1:

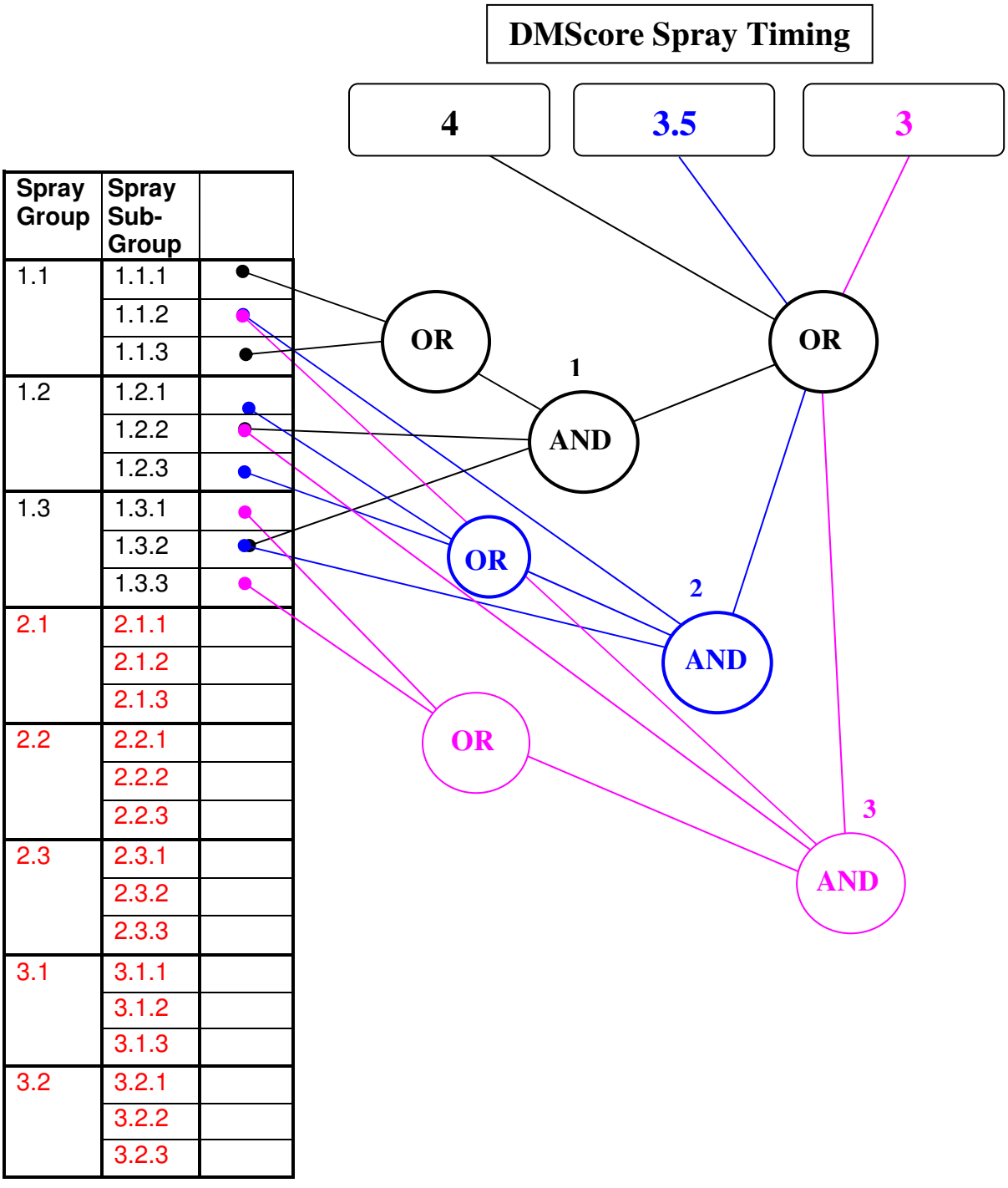
Diagram 2

2. Apply three sprays but one spray is a little early or a little late.

Where 1 = the first spray is applied within ± 4-6(7) days of target; or

2 = the second spray is within ± 4-6(7) days of target; or

3 = the third spray is within ± 4-6(7) days of target.



Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

Spray Group 1:

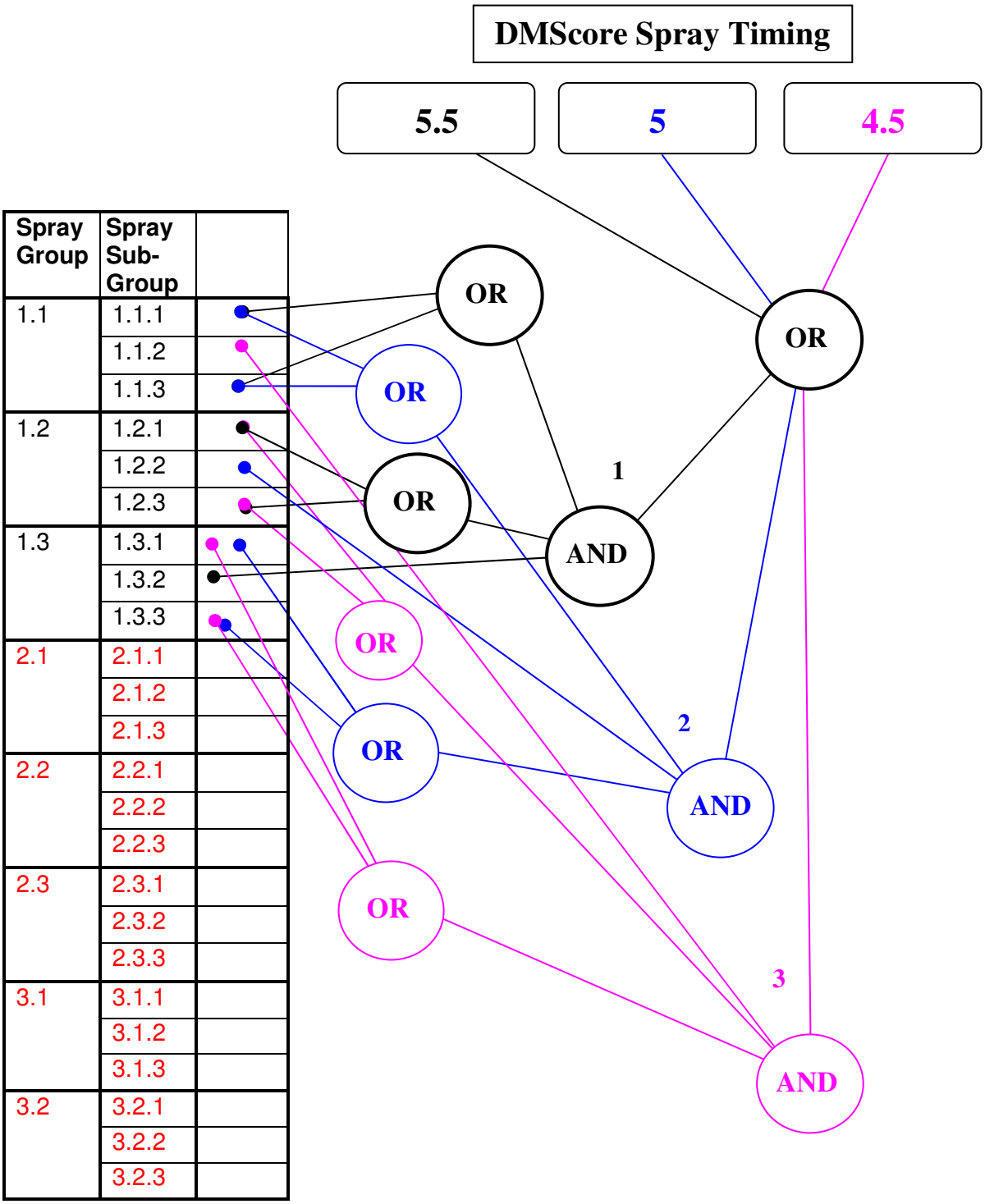
Diagram 3

3. Apply three sprays but two sprays are a little early or a little late.

Where 1 = the first and second sprays are within ± 4-6(7) days of target; or

2 = the first and third sprays are within ± 4-6(7) days of target; or

3 = the second and third sprays are within ± 4-6(7) days of target.



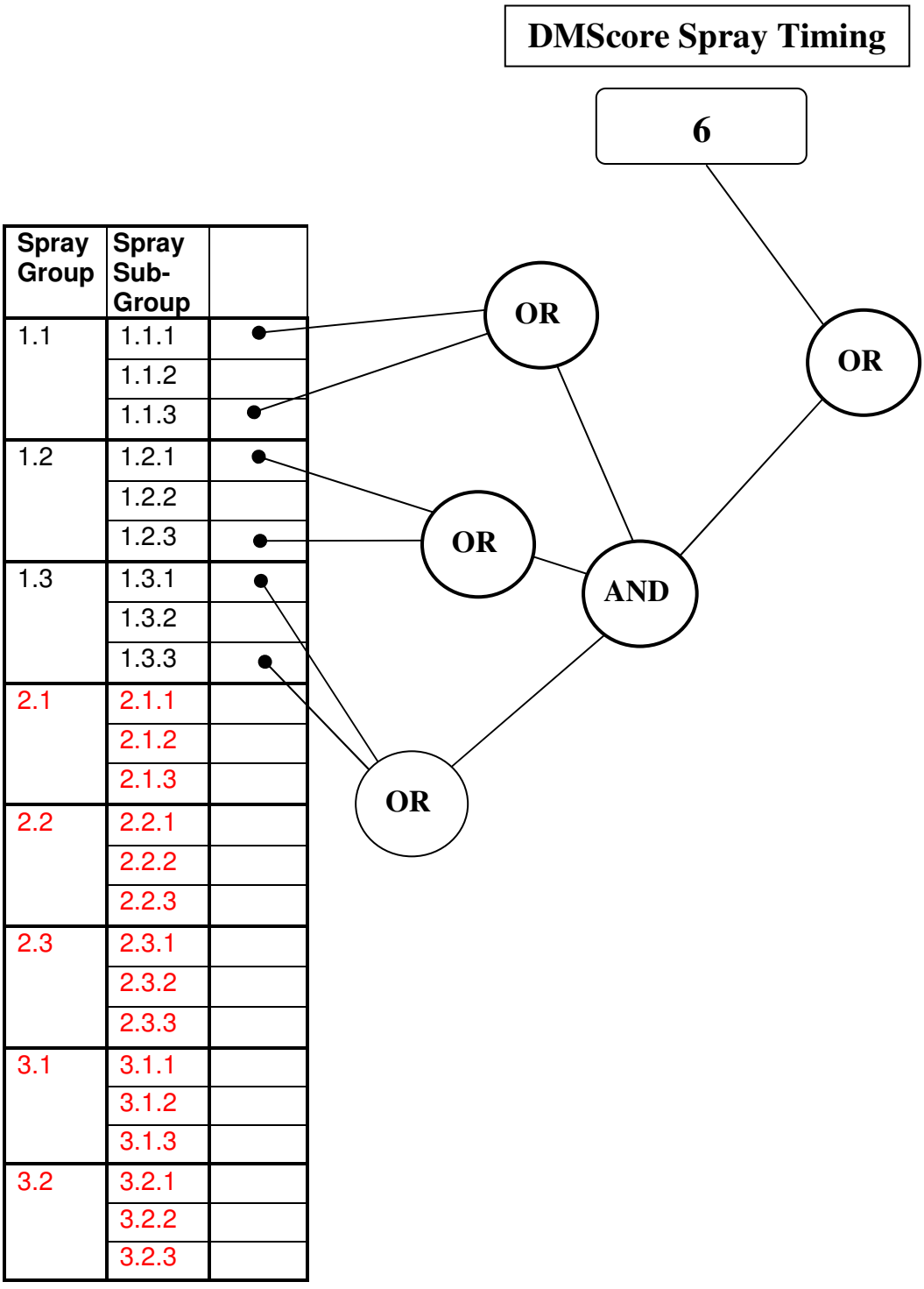
Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

Spray Group 1:

Diagram 4

4. Apply three sprays but all are a little early or a little late.

Where the first, second and third sprays are within ± 4-6(7) days of target.



Spray Group	Spray Sub-Group	
1.1	1.1.1	
	1.1.2	
	1.1.3	
1.2	1.2.1	
	1.2.2	
	1.2.3	
1.3	1.3.1	
	1.3.2	
	1.3.3	
2.1	2.1.1	
	2.1.2	
	2.1.3	
2.2	2.2.1	
	2.2.2	
	2.2.3	
2.3	2.3.1	
	2.3.2	
	2.3.3	
3.1	3.1.1	
	3.1.2	
	3.1.3	
3.2	3.2.1	
	3.2.2	
	3.2.3	

Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

Spray Group 1:

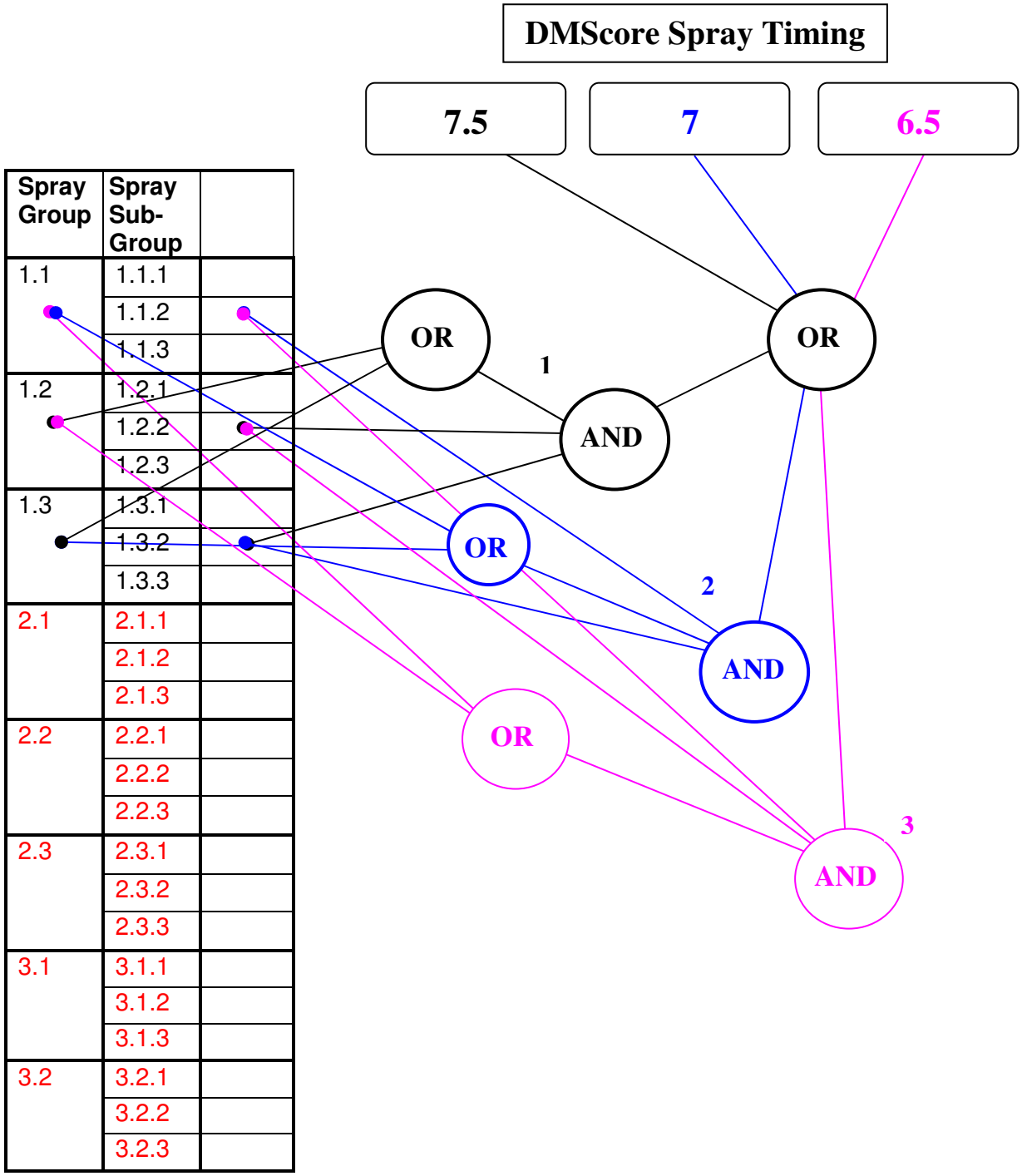
Diagram 5

5. Apply three sprays but one spray is too early or too late.

Where 1 = the first spray is applied > 6(7) days too early or too late (ie effectively is missed) and is applied in sub-group 1.2 or 1.3 instead; or

2 = the second is missed and is applied in adjacent sub-groups 1.1 or 1.3 instead; or

3 = the third is missed and applied in 1.1 or 1.2 instead.



Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

Spray Group 1:

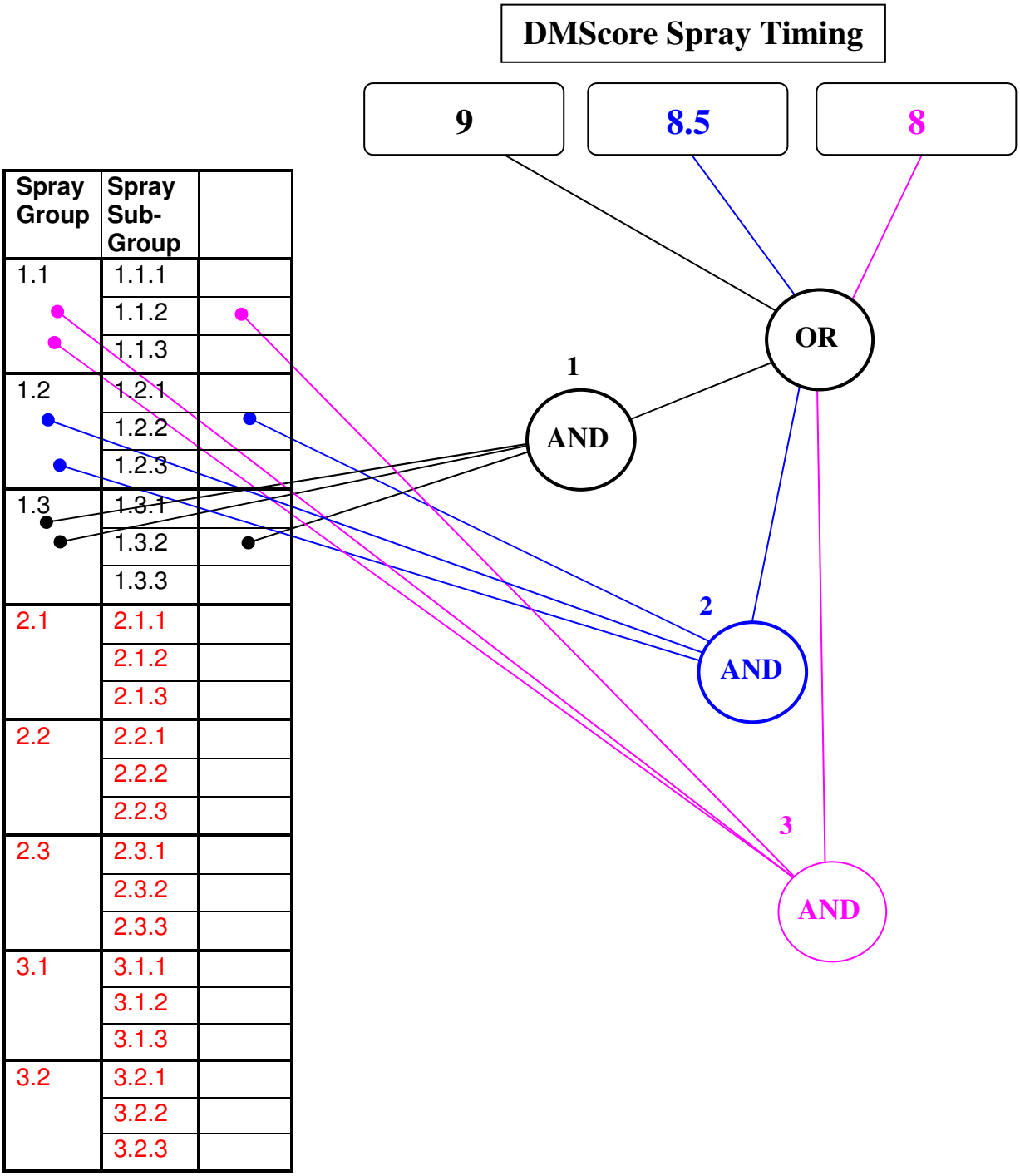
Diagram 6

6. Apply three sprays but two sprays are too early or too late.

Where 1 = the first and second sprays are applied > 6(7) days too early or too late (ie effectively are missed) and are applied in sub-group 1.3 instead; or

2 = the first and third are missed and are applied in sub-group 1.2 instead; or

3 = the second and third sprays are missed and applied in 1.1 instead.



Spray Group	Spray Sub-Group	
1.1	1.1.1	
	1.1.2	
	1.1.3	
1.2	1.2.1	
	1.2.2	
	1.2.3	
1.3	1.3.1	
	1.3.2	
	1.3.3	
2.1	2.1.1	
	2.1.2	
	2.1.3	
2.2	2.2.1	
	2.2.2	
	2.2.3	
2.3	2.3.1	
	2.3.2	
	2.3.3	
3.1	3.1.1	
	3.1.2	
	3.1.3	
3.2	3.2.1	
	3.2.2	
	3.2.3	

Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

Spray Group 1:

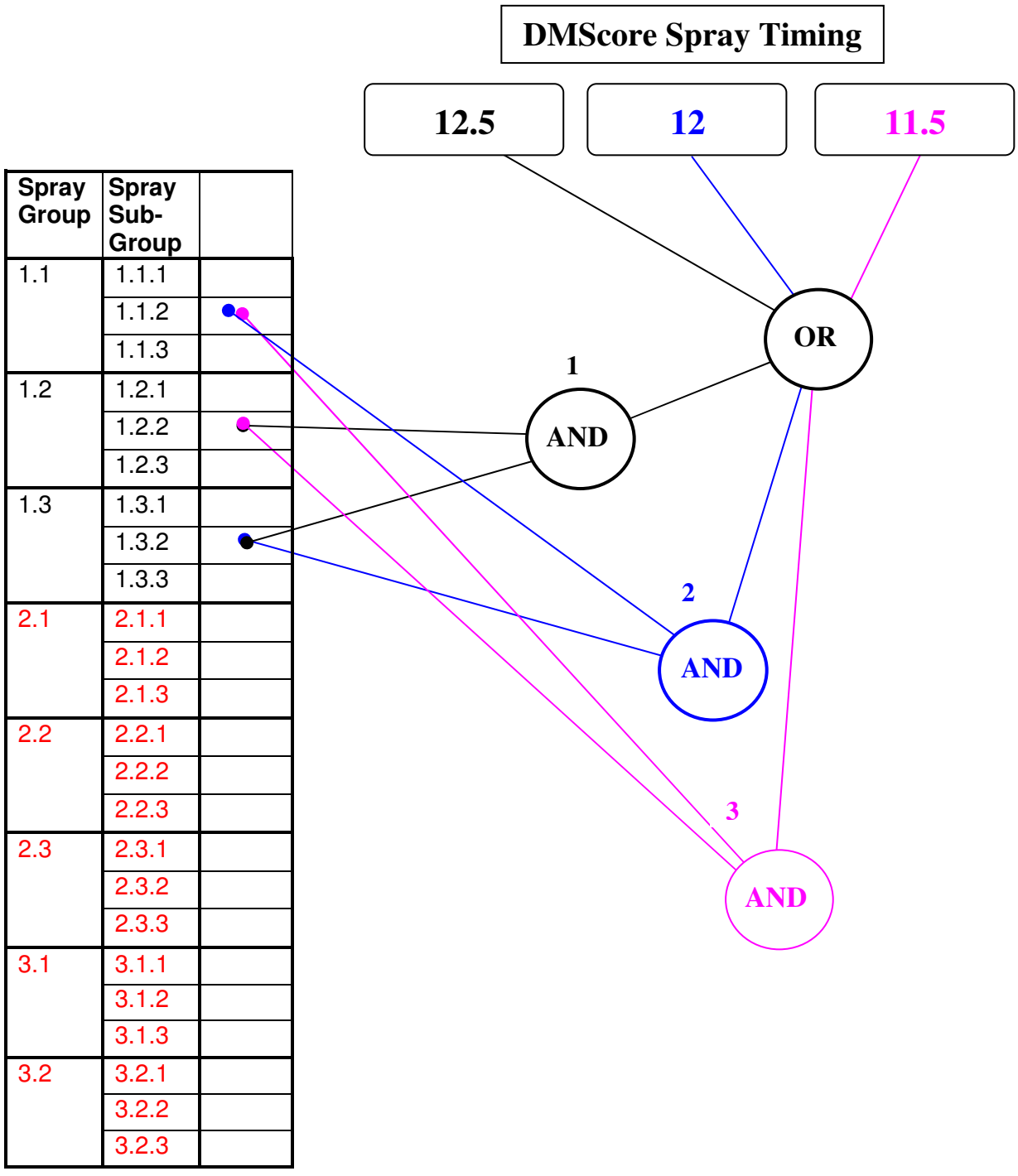
Diagram 7

7. Apply two sprays with excellent timing (ie one spray is missed)

Where 1 = the first spray is missed; or

2 = the second is missed; or

3 = the third is missed.



Spray Group	Spray Sub-Group	
1.1	1.1.1	
	1.1.2	
	1.1.3	
1.2	1.2.1	
	1.2.2	
	1.2.3	
1.3	1.3.1	
	1.3.2	
	1.3.3	
2.1	2.1.1	
	2.1.2	
	2.1.3	
2.2	2.2.1	
	2.2.2	
	2.2.3	
2.3	2.3.1	
	2.3.2	
	2.3.3	
3.1	3.1.1	
	3.1.2	
	3.1.3	
3.2	3.2.1	
	3.2.2	
	3.2.3	

Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

Spray Group 1:

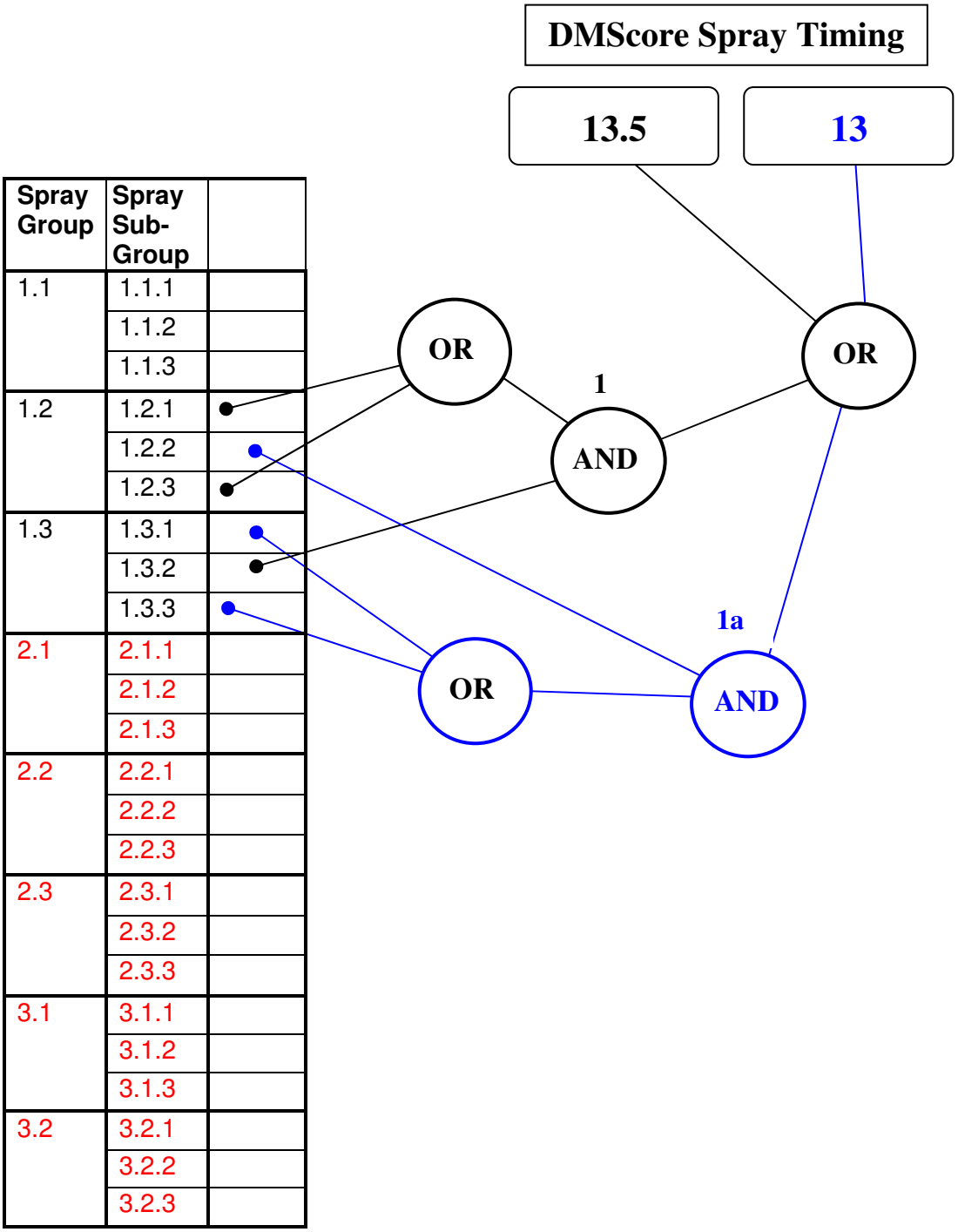
Diagram 8a

8. a) Apply two sprays but one is a little early or late.

Where 1 = the sprays are applied in sub-groups 1.2 and 1.3 and the spray within 1.2 is within ± 4-6(7) days of target; or

1a = the sprays are applied in sub-groups 1.2 and 1.3 and the spray within 1.3 is within ± 4-6(7) days of target.

Spray Group	Spray Sub-Group	
1.1	1.1.1	
	1.1.2	
	1.1.3	
1.2	1.2.1	
	1.2.2	
	1.2.3	
1.3	1.3.1	
	1.3.2	
	1.3.3	
2.1	2.1.1	
	2.1.2	
	2.1.3	
2.2	2.2.1	
	2.2.2	
	2.2.3	
2.3	2.3.1	
	2.3.2	
	2.3.3	
3.1	3.1.1	
	3.1.2	
	3.1.3	
3.2	3.2.1	
	3.2.2	
	3.2.3	



Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

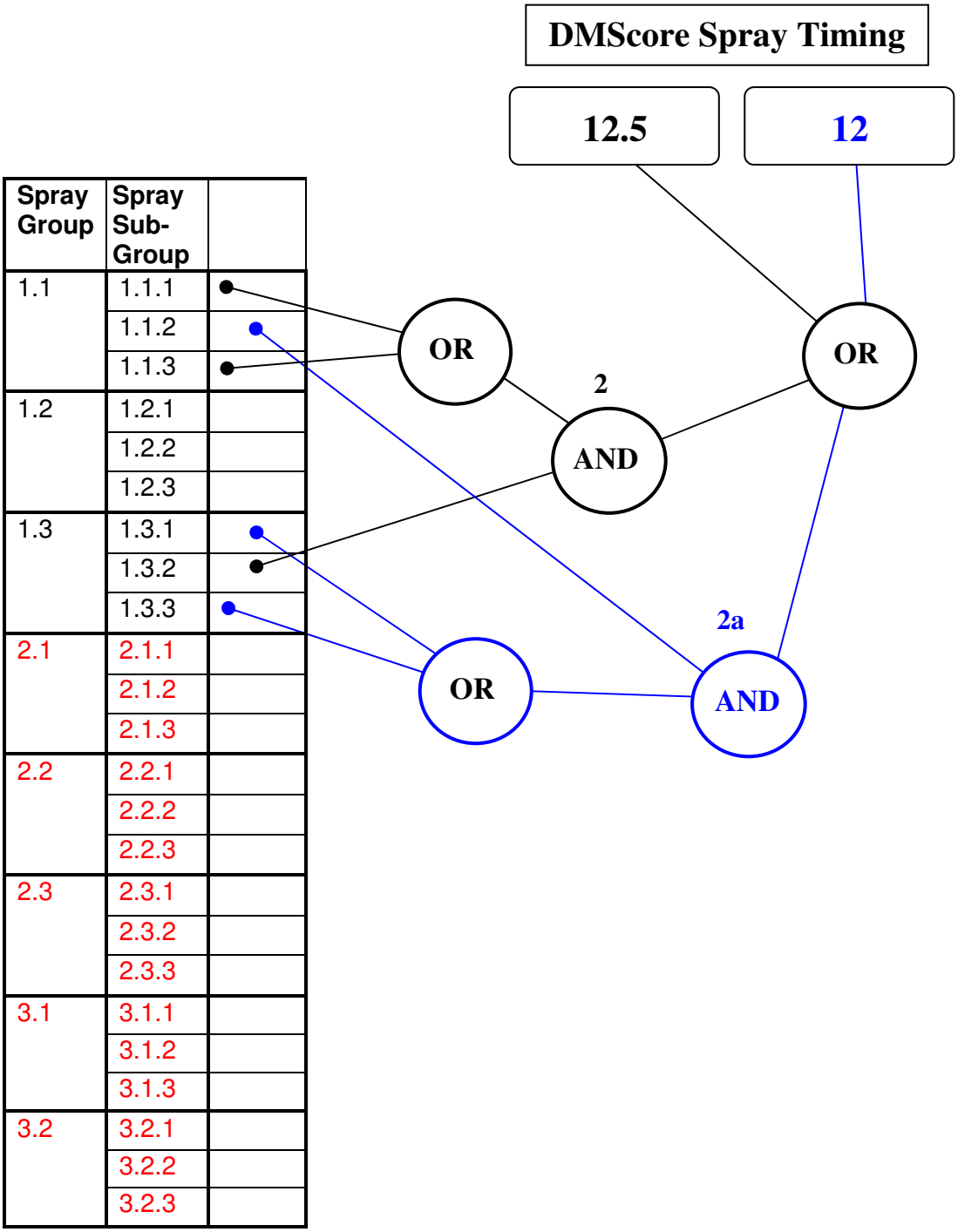
Spray Group 1:

Diagram 8b

8 b) Apply two sprays but one is a little early or late.

Where 2 = the sprays are applied in sub-groups 1.1 and 1.3 and the spray within 1.1 is within ± 4-6(7) days of target; or

2a = the sprays are applied in sub-groups 1.1 and 1.3 and the spray within 1.3 is within ± 4-6(7) days of target.



Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

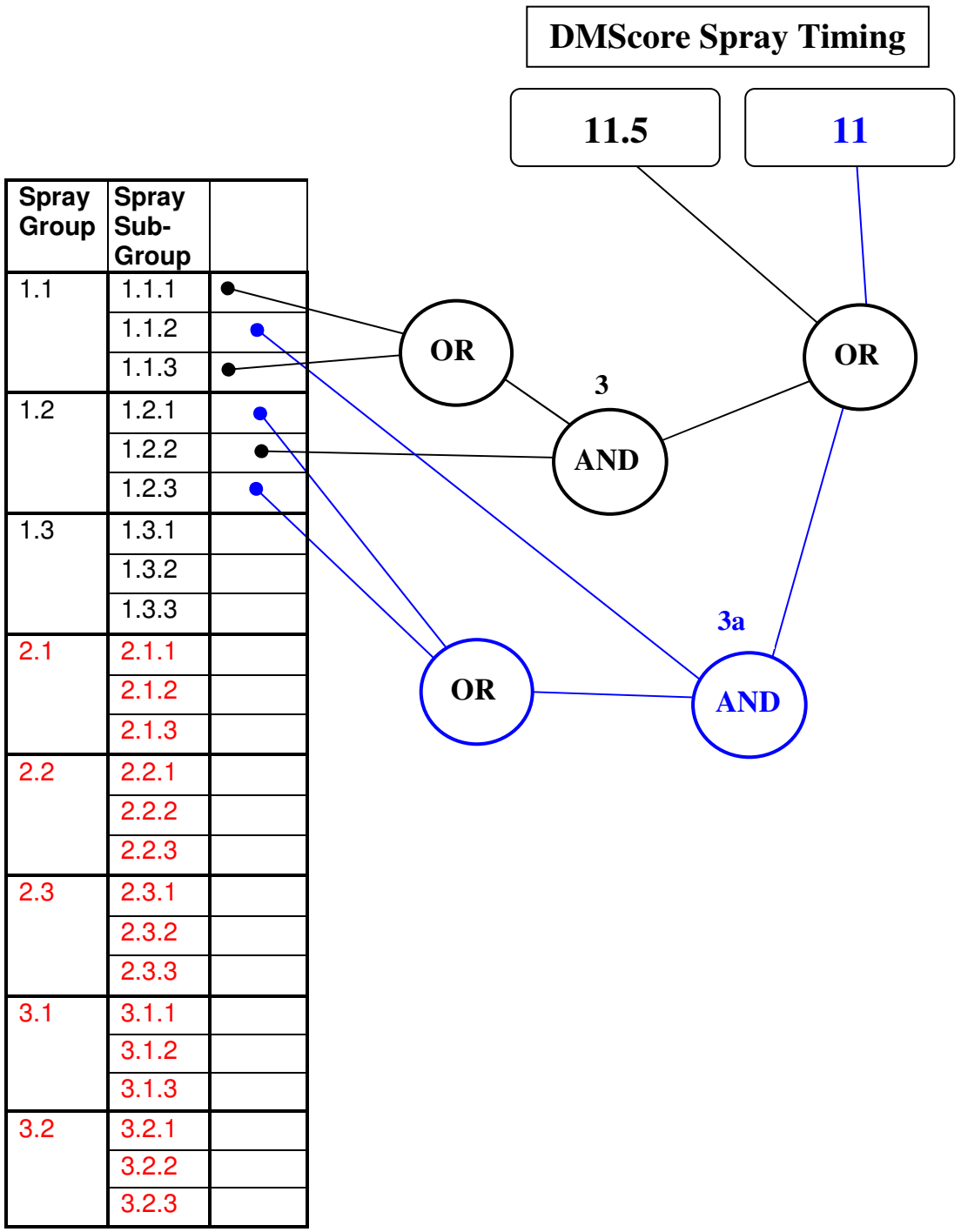
Spray Group 1:

Diagram 8c

8 c) Apply two sprays but one is a little early or late.

Where 3 = the sprays are applied in sub-groups 1.1 and 1.2 and the spray within 1.1 is within ± 4-6(7) days of target; or

3a = the sprays are applied in sub-groups 1.1 and 1.2 and the spray within 1.2 is within ± 4-6(7) days of target.



Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

Spray Group 1:

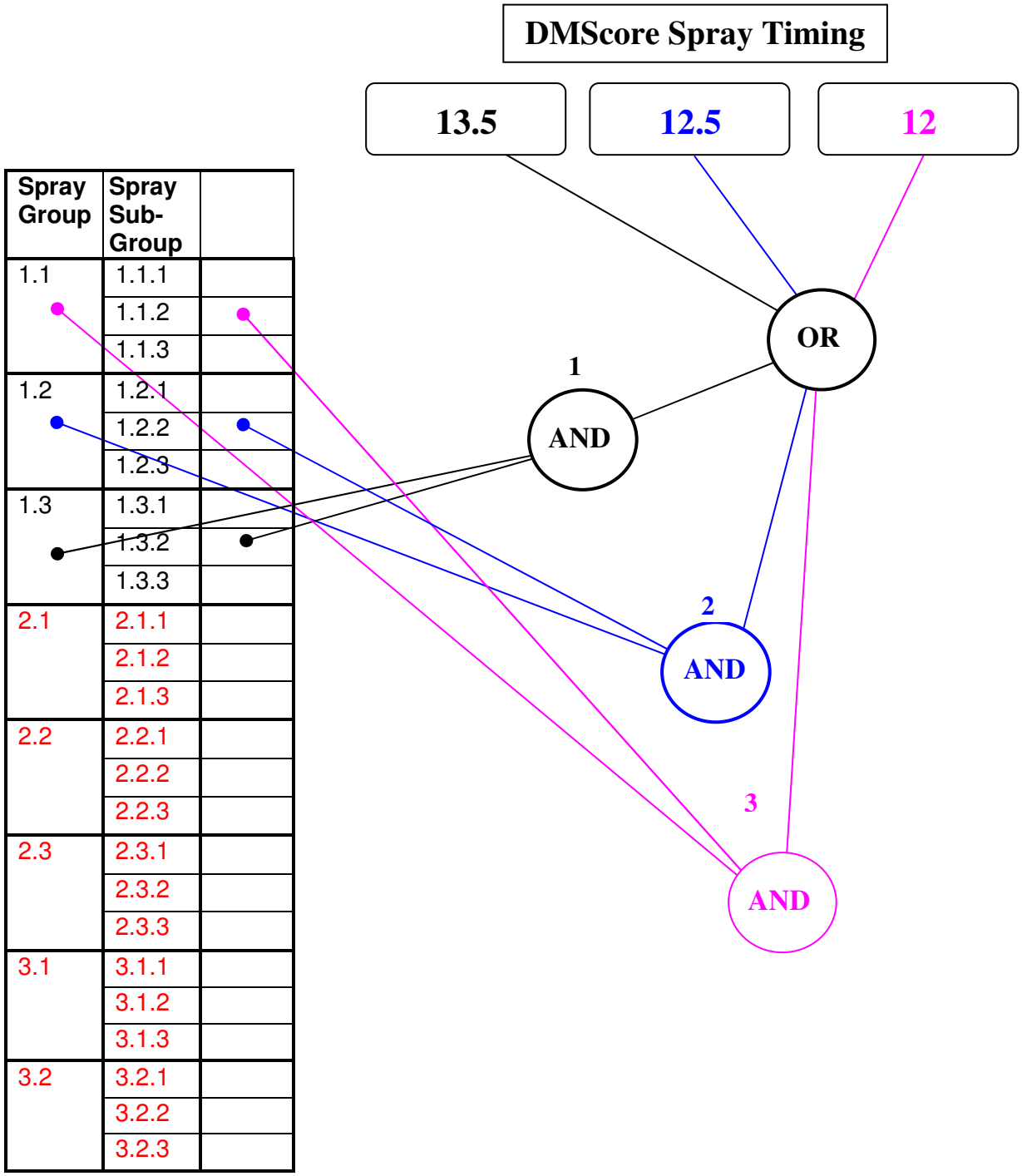
Diagram 9a

9. a) Apply two sprays but one is early or late (ie is missed) [nearly equates 1 spray with excellent timing]

Where 1 = the first and second spray are applied in sub-group 1.3; or

2 = the first and second spray are applied in sub-group 1.2; or

3 = the first and second spray are applied in sub-group 1.1.



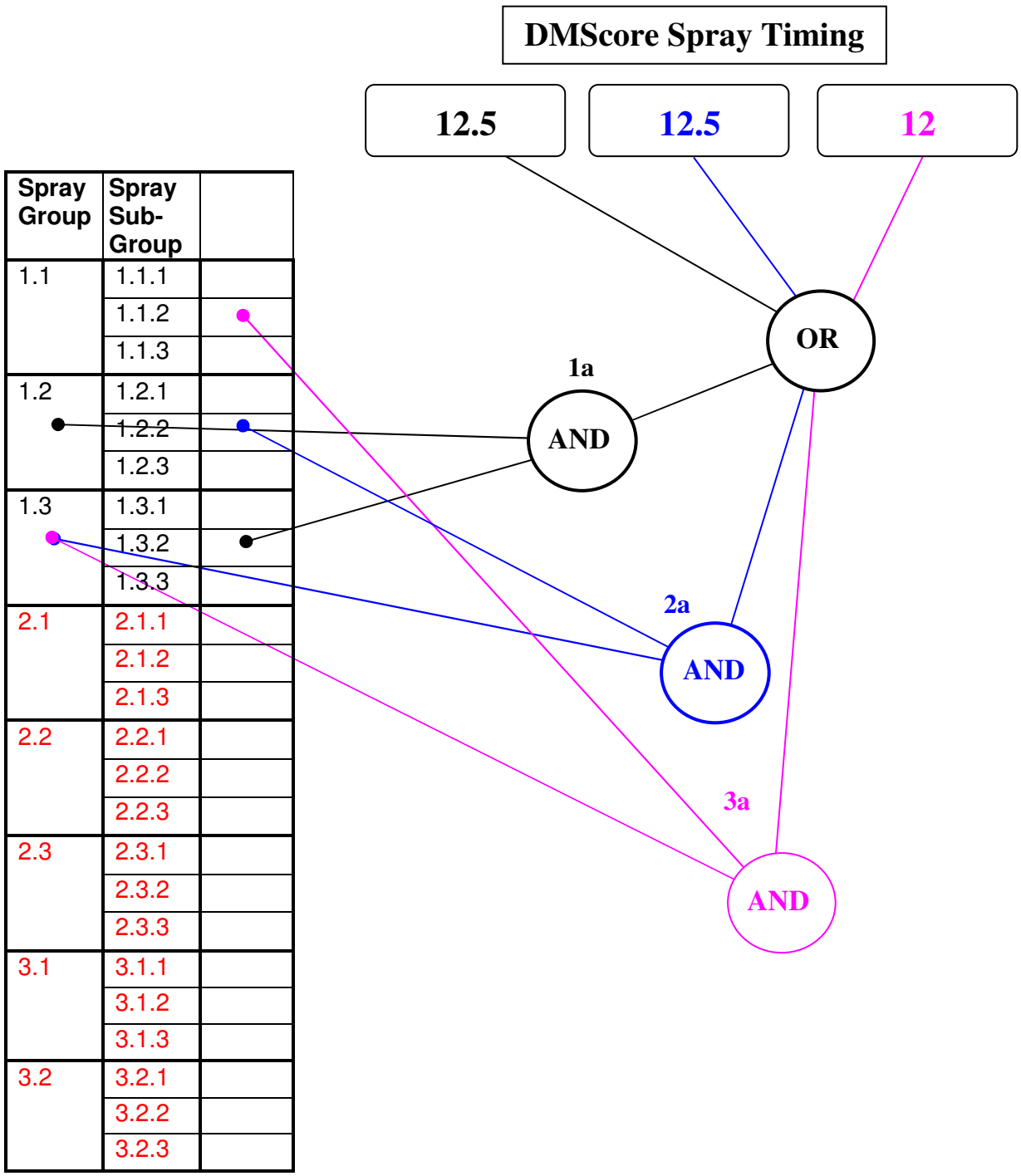
Spray Group	Spray Sub-Group	
1.1	1.1.1	
	1.1.2	
	1.1.3	
1.2	1.2.1	
	1.2.2	
	1.2.3	
1.3	1.3.1	
	1.3.2	
	1.3.3	
2.1	2.1.1	
	2.1.2	
	2.1.3	
2.2	2.2.1	
	2.2.2	
	2.2.3	
2.3	2.3.1	
	2.3.2	
	2.3.3	
3.1	3.1.1	
	3.1.2	
	3.1.3	
3.2	3.2.1	
	3.2.2	
	3.2.3	

Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

Spray Group 1:

Diagram 9b

9 b) Apply two sprays but one is early or late (ie is missed)
[nearly equates 1 spray with excellent timing]
Where 1a = the first is applied in sub-group 1.3 and the second in 1.2; or
2a = the first is applied in sub-group 1.2 and the second in 1.3; or
3a = the first is applied in sub-group 1.1 and the second in 1.3.



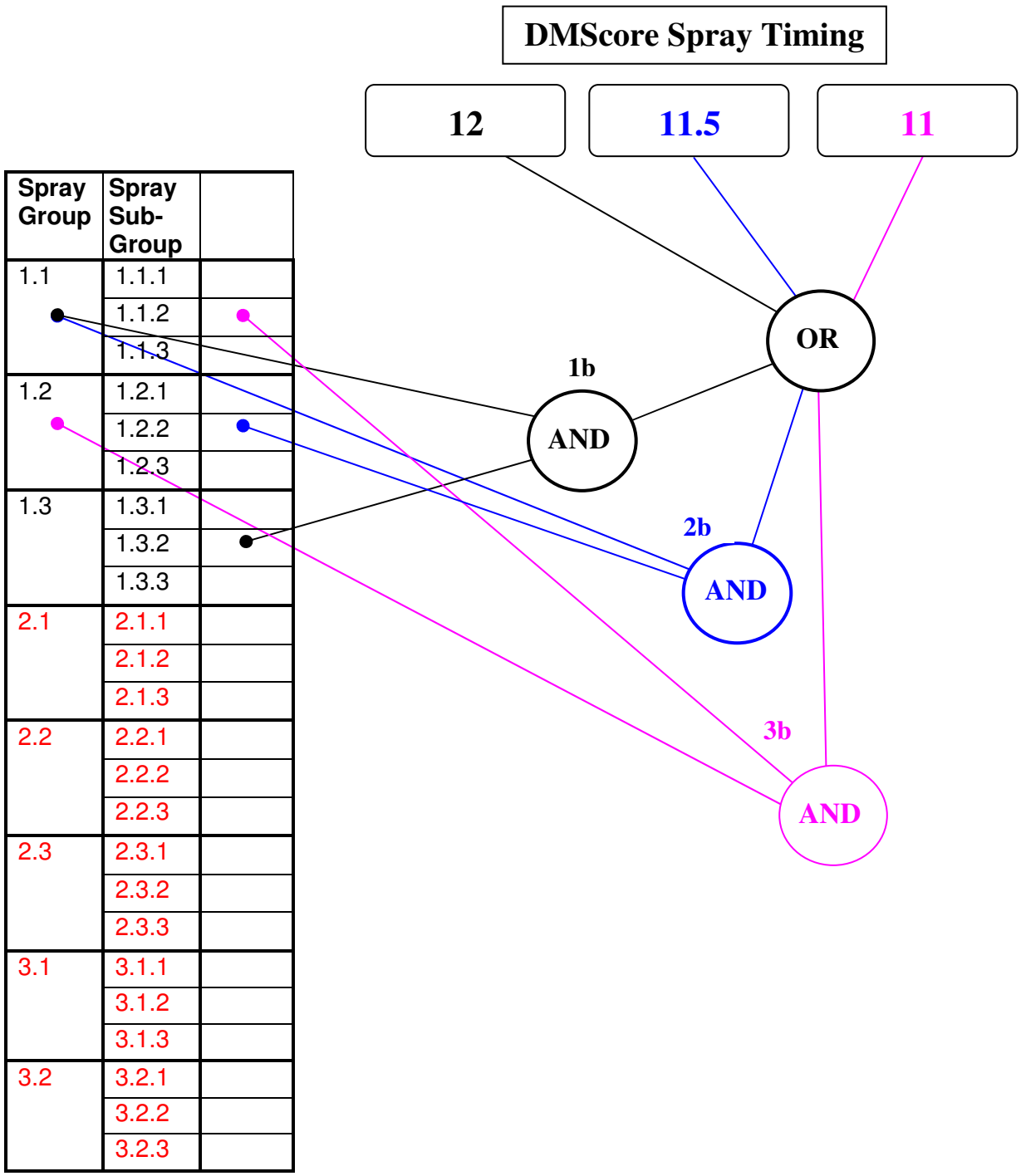
Spray Group	Spray Sub-Group	
1.1	1.1.1	
	1.1.2	
	1.1.3	
1.2	1.2.1	
	1.2.2	
	1.2.3	
1.3	1.3.1	
	1.3.2	
	1.3.3	
2.1	2.1.1	
	2.1.2	
	2.1.3	
2.2	2.2.1	
	2.2.2	
	2.2.3	
2.3	2.3.1	
	2.3.2	
	2.3.3	
3.1	3.1.1	
	3.1.2	
	3.1.3	
3.2	3.2.1	
	3.2.2	
	3.2.3	

Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

Spray Group 1:

Diagram 9c

9 c) Apply two sprays but one is early or late (ie is missed)
[nearly equates 1 spray with excellent timing]
Where 1b = the first is applied in sub-group 1.3 and the second in 1.1; or
2b = the first is applied in sub-group 1.2 and the second in 1.1; or
3b= the first is applied in sub-group 1.1 and the second in 1.2.



Spray Group	Spray Sub-Group	
1.1	1.1.1	
	1.1.2	
	1.1.3	
1.2	1.2.1	
	1.2.2	
	1.2.3	
1.3	1.3.1	
	1.3.2	
	1.3.3	
2.1	2.1.1	
	2.1.2	
	2.1.3	
2.2	2.2.1	
	2.2.2	
	2.2.3	
2.3	2.3.1	
	2.3.2	
	2.3.3	
3.1	3.1.1	
	3.1.2	
	3.1.3	
3.2	3.2.1	
	3.2.2	
	3.2.3	

Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

Spray Group 1:

Diagram 10

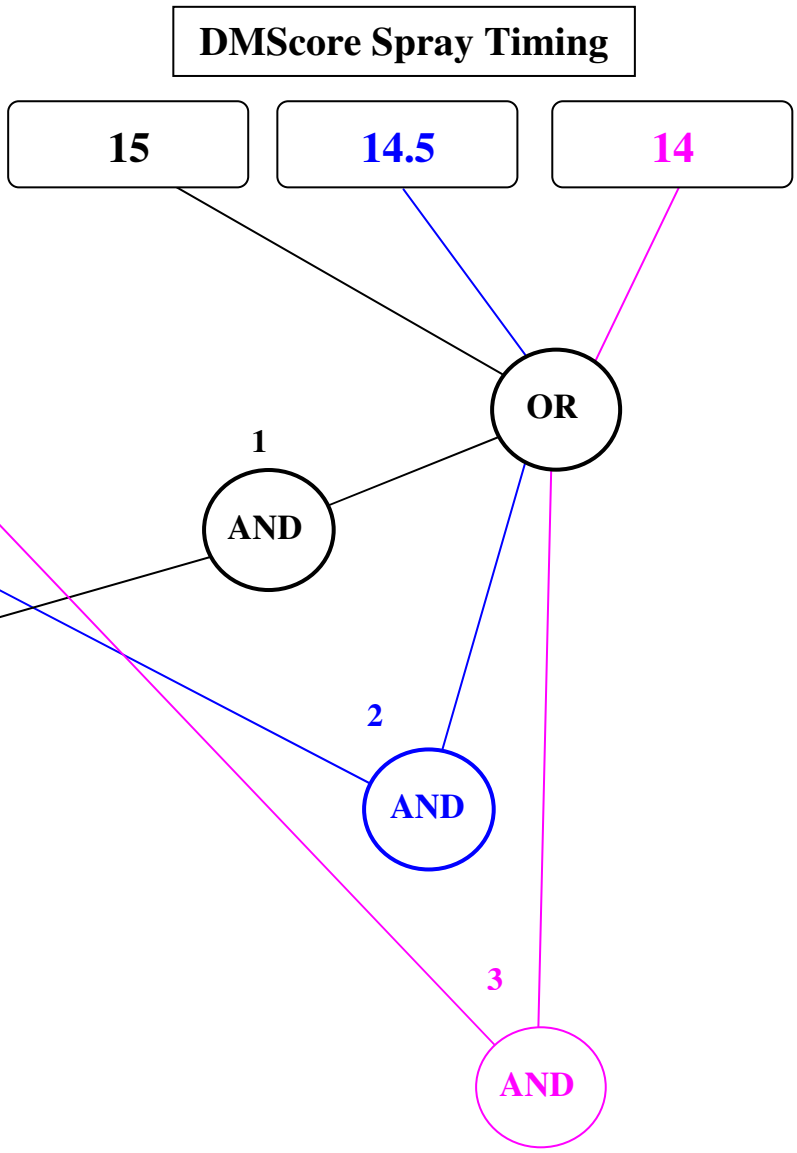
10. Apply one spray with excellent timing (ie two sprays are missed).

Where 1 = the spray is applied in sub-group 1.3; or

2 = the spray is applied in sub-group 1.2; or

3 = the spray is applied in sub-group 1.1.

Spray Group	Spray Sub-Group	
1.1	1.1.1	
	1.1.2	
	1.1.3	
1.2	1.2.1	
	1.2.2	
	1.2.3	
1.3	1.3.1	
	1.3.2	
	1.3.3	
2.1	2.1.1	
	2.1.2	
	2.1.3	
2.2	2.2.1	
	2.2.2	
	2.2.3	
2.3	2.3.1	
	2.3.2	
	2.3.3	
3.1	3.1.1	
	3.1.2	
	3.1.3	
3.2	3.2.1	
	3.2.2	
	3.2.3	

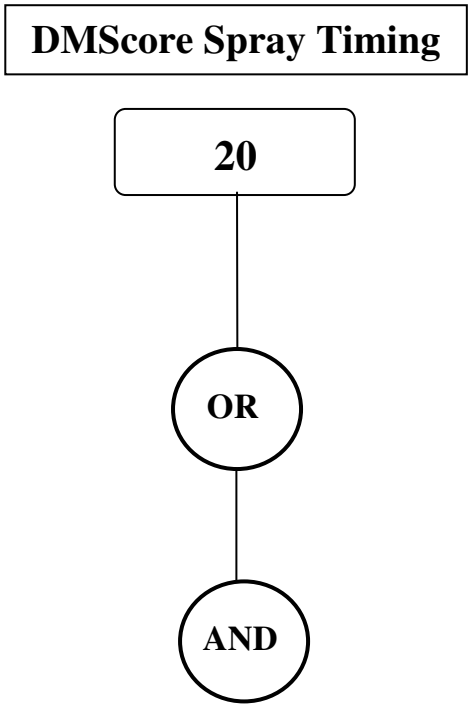


Appendix 3: Decision Networks for an Optimum Powdery Mildew Spray Schedule and Disease Management Scores for Spray Timing

Spray Group 1:

Diagram 11

11. Apply no sprays



Spray Group	Spray Sub-Group	
1.1	1.1.1	
	1.1.2	
	1.1.3	
1.2	1.2.1	
	1.2.2	
	1.2.3	
1.3	1.3.1	
	1.3.2	
	1.3.3	
2.1	2.1.1	
	2.1.2	
	2.1.3	
2.2	2.2.1	
	2.2.2	
	2.2.3	
2.3	2.3.1	
	2.3.2	
	2.3.3	
3.1	3.1.1	
	3.1.2	
	3.1.3	
3.2	3.2.1	
	3.2.2	
	3.2.3	