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Proceedings of the Science and Practice Workshop on grapevine powdery mildew

Beresford R
Plant & Food Research: Auckland

6 May 2015

Acknowledgements

Invited speakers: Damian Martin, Mark Eltom, Jerry Cooper, Peter Wood, Trevor Lupton, Kirstin Wurms, David Manktelow, Barbara Hall, Rob Beresford and George Follas

Workshop facilitator: Bob Fullerton

Meeting notes: Megan Jones, Rob Agnew and David Manktelow

Meeting logistics: Leonie Osborne

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This is an edited transcript of presentations and discussion during the Science and Practice Workshop on Grapevine Powdery Mildew and includes additional comments received from participants during preparation of these proceedings. This session does not reflect the views of New Zealand Winegrowers.

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Workshop objective

To help wine industry members and other stakeholders to understand the causes of the powdery mildew problem currently affecting New Zealand vineyards, and to develop a shared view about research and management that can lead to more reliable powdery mildew control.

Workshop programme

9.30 am	**Arrival & coffee**	
10.00	**1. Workshop introduction**	Damian Martin (PFR[1])
10.15	**2. Industry perspective on the current powdery mildew (PM) problem**	Mark Eltom (NZW[2])
Session 1	**Why has powdery mildew increased?**	
10.30	**3.** Asexual & sexual life cycles and evidence for origin of genetic types found in NZ	Jerry Cooper (LCR[3])
10.50	**4.** Chasmothecia in NZ; effects of weather, variety and vine growth on PM epidemics	Peter Wood (PFR)
11.10	Discussion	Led by Bob Fullerton (PFR)
Session 2	**Effectiveness of current control programmes**	
11.20	**5.** Current control programmes (timing and efficacy of various PM fungicides, canopy management, etc.)	Trevor Lupton (Lewis Wright Ltd)
11.40	**6.** The role of natural products and biological control agents in PM control programmes	Kirstin Wurms (PFR)
12.00	**7.** Spray application issues specific to PM management	David Manktelow (freshLearn Ltd)
12.20 pm	Discussion	Led by Bob Fullerton
12.30	**Lunch**	
Session 3	**Resistance to fungicides**	
1.00	**8.** Experience with fungicide resistance in Australia	Barbara Hall (SARDI[4])
1.30	**9.** Determining resistance for at-risk fungicides in New Zealand	Rob Beresford (PFR)
1.50	**10.** Action on resistance management	George Follas (NZCPR[5])
2.10	**Coffee break**	
Session 4	**The way forward**	
2.30	Discussion of key points noted from the three previous sessions	Led by Bob Fullerton
3.30	**Workshop close**	

[1]Plant & Food Research; [2]New Zealand Winegrowers; [3]Landcare Research; [4]South Australia Research and Development Institute; [5]New Zealand Committee on Pesticide Resistance

Workshop participants

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Key outcomes

- Evidence from Landcare's genetic marker research suggests PM strains in NZ are genetically distinct from those in North America, Europe and Australia, although further sampling is required to confirm this
- The sexual stage of the PM life cycle and associated chasmothecia have recently arrived in NZ, first being found in 2014. There is concern that genetic recombination via the sexual stage could give rise to new strains of PM that are more virulent and/or more resistant to fungicides
- Discussion about the implications of the sexual stage for disease management focussed on whether it could help explain the current PM control problems in vineyards and whether controlling chasmothecia could help disease management. In Australia, where chasmothecia have been present since the 1980s, presence or absence of chasmothecia is not a consideration in relation to PM disease management
- Participants felt strongly that research was needed to better understand the biology of PM in NZ, particularly the timing of chasmothecial production and ascospore infection and the relative importance of chasmothecial versus flag shoot overwintering in different NZ regions
- Grape berries are most susceptible to PM infection between about flowering and bunch closure and the most effective fungicide chemistry should be used at that time. PM must be well controlled in the leaf canopy by the early-season sulphur programme, because early leaf infection provides spores that infect fruit at the susceptible stage
- Associations between PM severity in NZ regions and climatic factors should be investigated to help explain the current PM problems and to determine whether weather-based prediction models would be useful for disease management
- Some PM control programmes are compromised by poor sprayer setup and poor spay timing. Higher lime sulphur rates (e.g. 5kg/ha) give better PM control. Natural products are available for PM control
- Fungicide application rates should be increased for narrow row spacings. Online tools are available through SWNZ for spray operators to compare and improve their spraying practices
- It is widely believed that fungicide resistance is reducing the effectiveness of DMI fungicides for PM control, particularly myclobutanil. However, there are also reports that DMIs are still working well. There was general agreement that research is needed to determine whether PM in NZ is resistant to DMI and QoI fungicides. A collaborative approach with the current Australian resistance testing project was recommended
- Fungicide resistance often affects products from multiple suppliers that are used in various different crops. ACVM requires resistance management statements to be placed on the labels of resistance-risk products. Resistance management strategies in NZ are coordinated by NZCPR (a committee of the New Zealand Plant Protection Society), for grape PM NZCPR will coordinate PM resistance management strategy revision in conjunction with the wine industry, agrochemical companies and researchers.

Introduction

1. Damian Martin (PFR) - The Plant & Food Research Grape & Wine Research Programme (GWRP) (Appendix 1)

2. Mark Eltom (NZW) – Industry perspective on the current powdery mildew problem

- NZW held a PM "think tank" earlier this year, for growers & PFR.
- Are the management implications with PM from practice issues or from chemistry falling over? – probably a combination of both
- A NZW approach will consider all avenues, including but not limited to research ideas
- Outcomes from "think tank" were to be emailed to attendees of this workshop.

Session 1: Why has powdery mildew increased?

3. Jerry Cooper (Landcare) – Grape PM genetic studies (Appendix 2)

- Grapevine PM originally evolved in North America.
- Two types of PM are recognised worldwide (from genetic markers): A and B, both of which occur in overseas vineyards (Europe & the USA). B is associated with more severe disease.
- In Landcare's recent NZ sampling of 37 isolates, Type A was only found in two samples from a Christchurch home garden. All the NZ vineyard samples were Type B. NZ Type B had two different populations, NZ1 and NZ2, both different from currently known populations elsewhere in the world. NZ2 appeared to be associated with high disease and presence of chasmothecia.
- PM mating type ratio (expected ratio = 1:1), was 6:1 for Type B-NZ1 and 4:3 for Type B-NZ2 in a limited sample. The source of the possible ratio imbalance for Type B-NZ1 is unknown, but the data support B-NZ2 and B-NZ1 being different strains.
- Occurrence of Type BNZ-2 appeared to be associated with presence of chasmothecia, greater severity and disease management problems.
- The absence of Type A from vineyards could be affected by sampling date and it is possible vineyard PM populations will change during a season.
- Further sampling is required to confirm all the above observations.

4. Peter Wood (PFR) - Grape powdery mildew: Chasmothecia in NZ and effects of weather, variety and vine growth on epidemics (Appendix 3)

- PM chasmothecia were first found in NZ in 2014 and have now been found in all major NZ wine regions.
- In southern France, Type A (flagshoot) isolates disappeared during the growing season. Type B (sexual) isolates were present for the entire epidemic, produced chasmothecia, and caused greater crop damage.
- Overseas, chasmothecial production peaks in mid- to late-season. After they wash from leaves, they overwinter in the bark. Ascospores are released between budburst and bloom after rainfall when temperature is >10^{o}C. Ascospore release has been modelled in Italy.
- In NZ we need to know whether chasmothecia contribute to early-season inoculum; how to kill chasmothecia; and what is the timing of ascospore release.
- Optimum PM weather is warm days (20-28^{o}C); cloudy skies (conidia killed by UV); high relative humidity; no rainfall (free water damages PM structures). Cold temperatures kill the fungus (2 h @ 2^{o}C). In NZ, hot summer conditions are unlikely to kill PM as they do in California. Leaves within shady vine canopies are more susceptible to infection.
- All classical varieties are susceptible, especially Chardonnay. PM damage to berries increases bunch rot.
- Grape shows ontogenic resistance to PM, i.e., tissues are susceptible when young. Fruit are highly susceptible for the first two weeks after fruit set. The PM epidemic on the fruit develops separately from that on the leaf canopy.
- PM develops faster in warmer springs, and a risk model could help to predict this so that sprays are timed better.

Session 1: Discussion

PM genetics and pathogen life cycle

- The industry wants to know about PM biology, and funding is needed to do this. We need to invest in basic research rather than just applied. This is not NZW's view.
- The genetics work provides a fundamental understanding of the pathogen, which will allow understanding of disease behaviour, development of optimum disease controls and understanding of fungicide resistance and its management
- Genetic recombination via the sexual stage is likely to increase the rate of fungicide resistance development.
- In Australia, there is no consideration of whether or not chasmothecia are present in relation to disease management. Genetics work that has been done in Australia is only on fungicide resistance markers.
- In NZ, it is possible the different B Type population may not be affected by ontogenic resistance in the same way as elsewhere, and this should be investigated

- The appearance of the sexual stage in NZ must have been from an incursion and could not have come about through mutation of the existing strain(s) in NZ.
- Recent arrival of the sexual stage cannot be managed like an incursion because not enough is known about when or where it arrived or how widespread it is.
- If disease control procedures are effective it may not matter whether it is Type A or B that is present; however, it is generally recognised that disease control procedures are often poor.
- Is there a susceptibility difference between Chardonnay and Sauvignon blanc?

PM control after harvest, over winter and primary infection

- PM development after vintage – is spraying ceasing too early? PM develops on late growth (especially in warmer climates where senescence is later). This contributes to overwintering, but would fungicide control of this help disease management in the following season? It is also not known whether this late infection leads to more chasmothecia being produced.
- In Australia, the critical time for PM sprays is spring; spraying also occurs later to manage leaf and rachis infection. Depending on the season, spraying may continue to the end of January.
- Infected buds and conidia don't survive winter in cold climates, so chasmothecia may be more important in southern NZ regions. Need to study development of chasmothecia and ascospore release in different regions. This will provide the basic biological information required to understand the disease and optimise control programmes
- Chasmothecia are washed down from leaves in autumn into the bark, but it is not known if canes or leaves on the ground are a source of spores.
- Chasmothecia are readily visible on vines with a 10x lens. In Australia, presence of chasmothecia doesn't affect disease management practices.
- There is no practical way to detect chasmothecia so they can be specifically treated. Pre-bud burst lime sulphur has been tried for killing chasmothecia, but efficacy needs to be established for NZ conditions. Lime sulphur was ineffective in Australia. Flowering is the critical time for fungicidal disease control.
- It may be possible to monitor ascospores at budbreak so they can be targeted with fungicides to prevent primary infection, or we could develop a predictive model to identify when ascospores are present, as in Italy.
- Chasmothecia are washed down from leaves in autumn into the bark, but it is not known if canes or leaves on ground are a source of spores.
- In Australia, fungicides over flowering are critical. Four sprays per season may be enough if control over flowering is effective. Need to manage new shoot growth and target sprays for different diseases to particular parts of the canopy. It is the whole vine canopy for PM.

Epidemic development and climatic risk

- Does season-to-season weather variation affect PM in a way that would allow: a) understanding of why epidemics occur in some years and not others, and b) development of a disease prediction model for disease controls? A weather risk study is needed to

determine whether this approach is worth following. The existing Gubler model would be a good starting point.

- Fruit damage is the main economic impact of PM, but the leaf canopy epidemic provides spores to infect fruit when they are susceptible. The leaf canopy epidemic must be well controlled - no bunch-line spraying for PM fungicides.
- PM is more difficult to control in northern regions because of higher humidity.
- Warmer temperature in northern regions shortens PM generation time and speeds up epidemic development.
- Cold spring temperatures decrease leaf susceptibility.
- Shady canopies favour PM because they increase humidity and increase leaf susceptibility.

Session 2: Effectiveness of current control programmes

5. Trevor Lupton (Lewis Wright) - Current control programmes (Appendix 4)

- From 2013 to 2015 PM became worse in Gisborne, Hawke's Bay and Marlborough.
- Vineyard sprayer performance is a common cause of poor PM outcomes. The type of sprayer used did not correlate with powdery mildew outcomes. Good and bad powdery mildew outcomes were found for all sprayer types.
- Spray diary analysis suggested that growers had better outcomes with use of 0-1 DMIs during the flowering to bunch closure period than growers who used 1-2 DMIs and additional late (post-bunch closure) DMI use. In Gisborne, better outcomes were seen in 2014 when DMIs were dropped from programmes.
- In grower case studies, PM control was improved by optimising sprayer setup and coverage, avoiding DMIs, mixing protectant and eradicant fungicides, and changes to canopy management.
- Late dormant lime sulphur didn’t give much control and is expensive. Oil eradicates PM, but coverage is critical.
- Sulphur @ 5 kg/ha gave better control than @ 4 kg/ha.
- Spray coverage is critical and can be assessed with water sensitive papers or by spraying Surround® WP.
- For resistance management, mix sulphur with single-site fungicides. When PM is high, use protectants (sulphur) instead of single-site fungicides.

6. Kirstin Wurms (PFR) – The role of natural products (NPs) and biological control agents in PM control programmes (Appendix 5)

- Advantages of NPs: easy product registration because they are non-toxic to humans; environmentally safe; short withholding period, suitable for organic and conventional growers; not at risk from resistance
- Disadvantages: Difficulty with formulation and handling, phytotoxicity, short shelf life, inconsistent control, blockage of spray equipment, relatively expensive
- Commercially available NPs for PM: MIDI-Zen®, HML32®, Ecocarb®, Kumulus DF®, Serenade Max®
- NP1 and NP2 are PFR products that have been trialled and give good efficacy under trial conditions.
- Best practice for NPs – Good coverage is critical; using oils after véraison can delay ripening; watch compatibility with other products; watch phytotoxicity

7. David Manktelow (freshLearn) – Spray application issues specific to PM management (Appendix 6)

- Grape canopies are particularly difficult to spray, and spray deposition (poor coverage) and dose (too little chemical) are the key issues for PM.
- The 6- to 8-fold increase in canopy surface area (ha/ha) between spring (4 weeks after budbreak) and full leaf and the 1.5-fold increase in canopy area from wide row spacing (3 m) to narrow row spacing (2 m) mean adjustment of chemical rate for canopy is required.
- Spring adjustment is easily achieved by turning on more nozzles as shoots extend.
- Spray retention efficiency changes with growth stage: bare canes 5%; 4 weeks after budbreak 20%; flowering 50%; maximum at bunch closure 80%.
- As the canopy grows, a constant product rate/ha all season would give 30-40% less deposit/leaf at full leaf than at 4 weeks after budburst, but the increase in spray retention efficiency helps to maintain the dose. The impact of row spacing on coverage is the factor being neglected.
- For benchmarking spraying practices, SWNZ has new tools for spray operators to compare their spraying practices with those of the rest of the industry, including spray application volumes, PM application intervals and sulphur application rates.
- Sulphur is being under-dosed in 40% of blocks.
- To optimise sprayer setup: confirm spray coverage, adjust product application rate for the canopy target, use appropriate application intervals, and choose products for efficacy, pre-harvest interval and resistance management.

Session 2: Discussion

- All the information required to spray grapes effectively against PM is available, but needs to be delivered in a way that spray operators can use.
- Vineyard owners need to monitor contractors so they know what's actually happening, because data are not being recorded.
- Spraying performance should be a paid criterion for contractors, so they ensure their equipment is up to the job. There is not enough equipment in each region for all the spraying in difficult seasons.
- The wine industry could consider funding a national programme of PM efficacy testing for natural products, covering efficacy, phytotoxicity and timing. A structured approach, like the one Zespri used for Psa product screening, would provide definitive information about efficacy and phytotoxicity. This point is not a reflection of the NZ wine industry, it was a discussion point raised by PFR.
- Could copper be a forgotten tool for powdery mildew control?

Session 3: Resistance to fungicides

8. Barbara Hall (SARDI) – Fungicide resistance in Australian vineyards (Appendix 7)

- The "Understanding fungicide resistance in viticulture" project (2013-2016) has multiple funders and is looking at resistance in botrytis, downy mildew and powdery mildew at the regional level throughout Australia. Cost over 3 years of A$1.3 million. It aims to develop methods for testing, determine degree and distribution of resistance and develop resistance management strategies.
- Resistance testing uses plant-based assays for phenotyping and compares these with genetic tests for resistance gene mutations.
- Considerable technical challenges working with PM, because it is a biotroph that can grow only on living plant material. Often unable to be isolated from leaf samples sent by growers. Contamination of colonies by other fungi is a big problem.
- Young Cabernet Sauvignon leaves are used for testing on leaf discs. Ecocarb® (potassium bicarbonate) sprays are used in the growth room to keep test plants mildew-free.
- Tests are done with single spore isolates. EC_{50}s (concentration that inhibits growth by 50%) are determined from five fungicide concentrations.
- PM phenotyping results showed 38% of 47 isolates from five States had reduced sensitivity to pyraclostrobin (Cabrio®) and 24% had reduced sensitivity to penconazole (Topas®).
- Pyraclostrobin showed good agreement between phenotyping and genotyping (G143A), whereas penconazole did not.
- PM resistance to QoIs (strobilurins) is widespread and closely related to exposure to QoI fungicides over the last two years. Reduced sensitivity to DMIs is present and is linked to exposure to DMI fungicides. So far the project has not linked the degree of resistance found in testing to failure of field disease control.

9. Rob Beresford (PFR) – Determining resistance to at-risk fungicides in New Zealand (Appendix 8)

- Poor disease control can be caused by wrong product choice, poor timing, poor coverage or fungicide resistance.
- Evidence in NZ for PM resistance is currently anecdotal. Resistance causes disease control problems in seasons with weather favourable for disease, when spray programmes are sub-optimal and when the fungus can easily undergo genetic recombination. Use of at-risk fungicides when disease is severe helps rapid resistance development. All these things have been present in NZ vineyards over the last 3 years.
- Suspicion that resistance is present causes loss of confidence in fungicide products, potential litigation over failed products, costs in developing new chemistry, and costs in redesigning spray programmes.
- A resistance testing programme is required to determine the extent to which resistance is present in NZ vineyards and contributing to PM control problems.
- There are five fungicides groups at risk from PM resistance, but only two (DMIs and QoIs) are of immediate concern. Testing of the other three groups is important to determine baseline sensitivity, to monitor for future development of resistance.
- A detached leaf assay for phenotyping PM resistance was developed in 2014. A test of four Hawke's Bay PM isolates showed a possible loss of sensitivity to myclobutanil.
- Over 400 powdery mildew isolates were collected in March 2015 for possible testing this winter, depending on a source of funding for the work.

10. George Follas (NZCPR) – New Zealand Committee on Pesticide Resistance (Appendix 9)

- NZCPR comes under the New Zealand Plant Protection Society. Its role is to develop and publish strategies for preventing and managing resistance in all crop protection pests (fungi, bacteria, insects, mites and weeds).
- Rationales for resistance strategies are published in scientific review papers and NZPPS books, and guidelines are placed on product labels and on the NZPPS website: http://resistance.nzpps.org/.
- Strategy development requires knowledge of the mode of action (MOA) of fungicides and stored monitoring data to detect resistance development. MOA information usually comes from published research and MOA codes developed by FRAC are followed.
- The Agricultural Compounds and Veterinary Medicines Act 1997 (ACVM) requires mandatory MOA and resistance statements on product labels. MOA charts for currently available pesticides in NZ are on the NZPPS website.
- Resistance management involves reducing use of the at-risk pesticide and alternating or mixing it with other effective pesticides that are not at risk from resistance.
- Effective management of the resistance problem in grape PM requires: 1) research to define the problem, 2) a task group to coordinate information, 3) revised strategies, and 4) communication of strategies among NZCPR, researchers, wine industry, and agrochemical companies.

Session 4: The way forward – overall discussion

Questions about the sexual stage, disease cycle and climate

- Viticulturalists now find PM more difficult to control, and the reasons for increased severity need to be understood.
- Has the organism changed to become more aggressive?
- How much of the PM problem is climatic from three dry seasons, and would a change to wetter seasons reduce severity?
- Regional/sub-regional differences: In 2014-15, Marlborough growers noticed PM was more difficult to control in the Awatere Valley than in the southern valleys (Wairau Valley). Regional differences could reflect cultivar mixes, e.g., Chardonnay and Gewürztraminer are more susceptible.
- When are chasmothecia formed and are there regional differences? How do dry versus wet winter conditions affect overwintering? Chasmothecial populations decrease over winter in Australia as a result of rainfall events. A study in multiple NZ regions is needed to investigate chasmothecial development and ascospore release. This could be compared with Australian experiences and if the pattern were the same, then Australian experience could be used to manage PM in NZ.
- If PM is kept under control during the season, then chasmothecia won't form and many of the questions won't matter. However, to achieve improved control, some of the questions will need to be answered.
- If PM is well controlled all season, few chasmothecia will form.
- Can the woody tissue (cordon) on dormant vines be treated to eliminate chasmothecia?
- How important is post-vintage disease development in contributing overwintering inoculum for next season?
- Is the disease risk still building, i.e., are chasmothecia numbers still increasing?
- We need to examine historical weather data (e.g. 10 seasons) and compare the last three "dry" seasons with others for possible differences that would explain the recent increase in severity. The Gubler risk model and Italian ascospore release models could be incorporated into this.

Questions about PM disease management

- Do we have a clearly stated programme of industry best practice?
- NZW practical guidelines booklet for industry – it is recognised that this is not an end in its self?
- Wine companies produce their own guidelines.
- Growers tend to look for prescriptions.
- Where growers get their information from:
    - NZW/ viticulturalists/chemical companies all need to be giving the same message.
    - Clearer information is required about vine phenology and spray timing.
    - Understanding what the pathogen is throughout the year and why it is important
- Broadening modes of action that can be used – with natural products integrated with synthetic fungicides
- Use a good adjuvant with sulphur at critical times
- Weather-based risk models – ground truthing for NZ.
- Does lime sulphur pre/early season have any effect? Do you get fewer chasmothecia?

Questions about PM fungicide resistance

- What is the time from reduced sensitivity to practical resistance affecting disease control?
- Would it help to rotate DMIs within a season? Australian researchers suggest alternating DMI actives, on the presumption that there are different degrees of resistance to different DMIs.
- Need research on resistance to prove whether disease control problems are resistance related
- Use of DMIs under high disease pressure will select for resistance more rapidly.
- Are resistance management guidelines strong enough?
    - Number of DMIs per season?
    - Always mix with protectants?
    - QoIs – should we be counting down the number of applications until resistance occurs (20 applications has been reported)?
- Need better information about products to use as mixtures to minimise risk of resistance.

Comments from Allan Clarke on the current powdery mildew problem

- The “major epidemic” last season and apparently sudden difficulty in controlling PM in Marlborough may be an overstatement of the situation. PM builds up over several seasons to create a major epidemic.
- It was only 3 years ago that we had a downy mildew epidemic in Hawke’s Bay and PM was not considered a particular problem. It begs the question as to whether these diseases are responding to seasonal weather when spray schedules are compromised in the quest to be residue free under the sustainable programme adopted by the industry in recent years.
- Industry spray schedules need to be checked to ensure they fully cover the high risk period for PM: flowering and the 6-8 weeks of bunch development that follow.
- Myclobutanil has come under scrutiny as the chemistry that is failing as possibly new and more resistant strains of PM are appearing in the New Zealand population. There are in fact good and poor reports on myclobutanil efficacy and often the poor results are from poor timing of the first application of mildew-specific products. However, loss of efficacy of the DMI group should be tested in New Zealand, in collaboration with Australia.
- Spray coverage is important and there is the need to get product on to the flowers as well as the foliage. In vigorous New Zealand vineyards a light leaf pluck just prior to flowering would help to achieve the required coverage. Leaf plucking is relatively cheap.

For circulation to:

Wine industry and agrochemical industry participants

This is an edited transcript of presentations and discussion during the Science and Practice Workshop on grapevine powdery mildew and includes additional comments received from participants during preparation of these proceedings. This session does not reflect the views of New Zealand Winegrowers.

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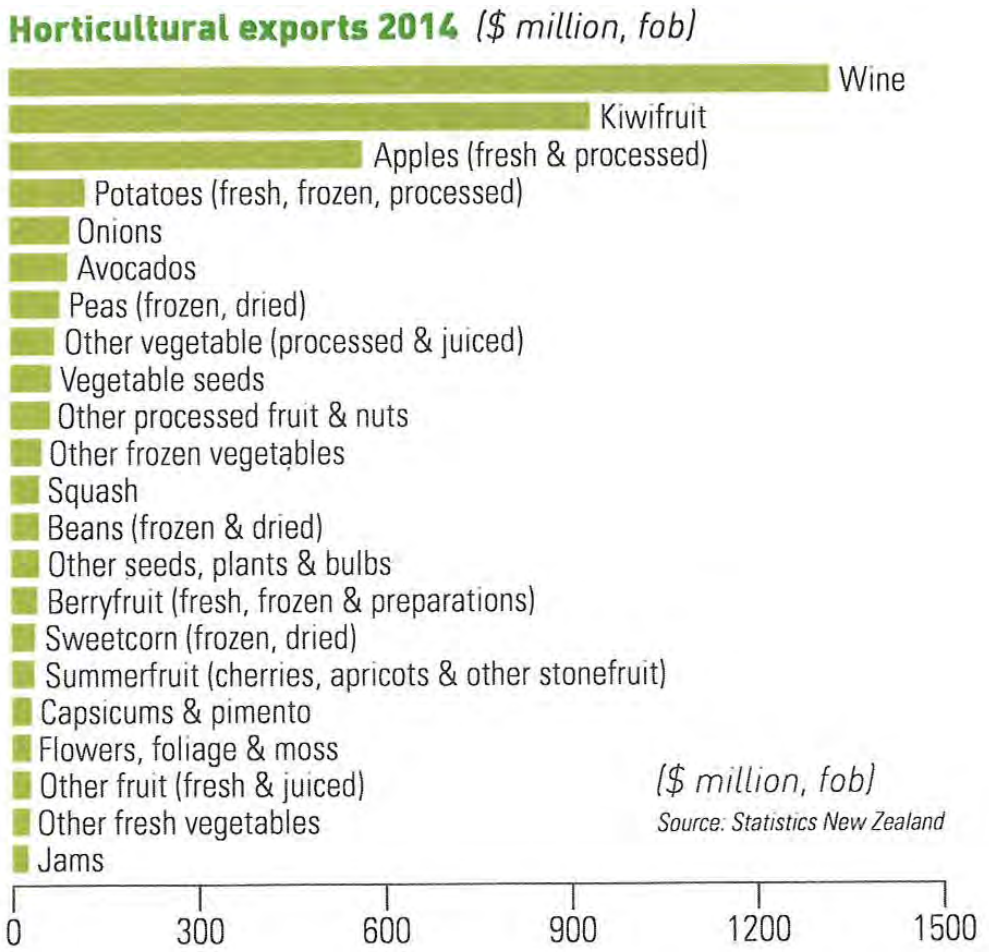
Appendix 1. Damian Martin

The New Zealand Institute for Plant & Food Research Limited

The New Zealand Grape & Wine Research Programme (GWRP)

Damian Martin
May 2015

New Zealand's largest horticultural export



Source:
Fresh Facts 2014

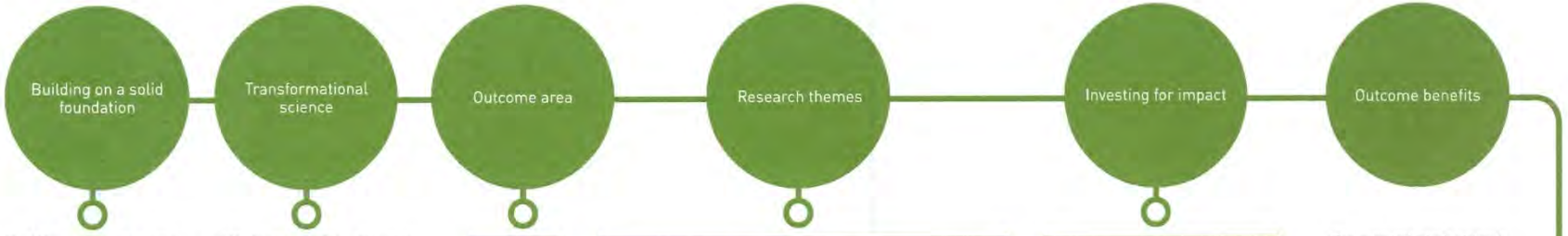
New Zealand's largest horticultural export

- June 14 year $1.33B
- 6th largest export sector
- National GWRP budget of ca. $7.0M
- **Key partners:**
  - New Zealand Winegrowers (NZW)
  - Plant & Food Research
  - University of Auckland (UoA)
  - Lincoln University
- NZW/MBIE Partnership recently approved
- Members rate R&D most valued NZW service*

*Source: NZW Annual Report 2014

Wine sector

ROAD MAP TO IMPACT



Building on a solid foundation

The NZ wine industry earns around $2.34B pa of which $1.21B is from exports, $630M is from international wine tourist spend and $500M is from sales in NZ. This makes the wine industry the most valuable horticultural exporter and the 8th most valuable exporting sector in NZ.

Five Māori-owned organisations are involved in wine making.

More than 800 growers and 700 wineries grow over 270,000 t of grapes and produce over 194,000 L of wine.

Transformational science

PFR's Grape and Wine Research Programme is a partnership with NZ Winegrowers and is focused on building NZ's competitive advantage and profitable growth in sales.

Research priorities, based on existing and developing capability, are:

- Cost-efficient delivery – increasing the yield and quality of grapes and predict seasonal variations
- Disease management – decision tools to better manage the risk of grape-crop losses and maintaining the residue-free status of NZ wines
- Future protection – strategies and plans to mitigate threats
- Protect premium position – innovative viticultural and wine-making practices to refresh existing NZ wine styles and new premium styles
- Vineyard longevity – cost-effective tools to eradicate and manage pests and diseases that threaten grapevine health.

Key customers and collaborators include:

- NZ Winegrowers
- Marlborough Research Centre
- Lincoln University
- University of Auckland.

Outcome area	Research themes	Investing for impact
Residue-free pest and disease control	• Developing enhanced and new bunchrot disease control tools and practices from new knowledge in vineyard pathogen biology, ecology, host genetics and vineyard microbiology • Understanding the life cycle and epidemiology of second-tier fungal diseases and developing growing practices to manage their effects.	By 2021 grape growers will be using web-based decision tools to better manage bunch rot diseases, reducing mitigation costs by up to $1.6-5.6M pa and maintaining residue-free status.
Residue-free pest and disease control	• Control systems for existing terminal disease vectors and new surveillance systems for potential pest incursions • Cost-effective management practices for terminal diseases such as grapevine leafroll and trunk disease • Producing rootstocks with attributes that reduce the cost of grape production and contribute to vine longevity.	From 2016 new tools to increase the average lifespan of vineyards from 25 to 35 years will be implemented and preparedness plans to protect the national vineyard from imminent pest and disease threats will be in place.
Sustainable and profitable production systems	• Predicting yield potential at regional and sub-regional levels to guide timely and cost-effective management • Predicting the timing of key phenological stages to forecast potential crop loss risk from climatic and environmental events and developing mitigation strategies that maintain wine quality.	From 2018 the wine industry is using predictive models to produce more reliable and consistent harvests, maintaining NZ wine's price premium by actively managing supply/demand and saving up to $1M-2M pa in yield management costs.
Proprietary foods with premium prices	• Establishing the roles of terroir, seasonality, viticultural practices and harvest technologies on wine style • Viticultural and winemaking tools to develop new wine styles • Identifying key components of aroma, flavour and mouthfeel that define sensory quality for target markets • Establishing a *Vitis* genetic resource for genetic studies and undertake trait inheritance research.	By 2023 sales of wine have increased to up to $2.34B pa by maintaining the freshness of existing NZ-branded styles and developing new and innovative styles of wine for new consumers.

Outcome benefits

The wine industry's vision is to increase export revenue to $2B by 2020. Research priorities to achieve this include pests and diseases, reducing costs and increasing profitability, sustainability and organics, quality wines for existing and developing markets, and technology transfer.

Our grape and wine research

Protecting the premium position of NZ wines

1. Protecting what differentiates NZ wines from international competition

» Characterise aroma and flavours that define NZ's key wine styles

» Predicting wine composition from juice chemistry

» Understanding environmental and seasonal influences

» Developing tools to manipulate juice/wine composition

Our grape and wine research

Cost efficient delivery of NZ wines to market

2. Maintain/enhance the international competitiveness of NZ wines

- » Prediction of yield at an early stage
- » Developing tools to mitigate against seasonal variation
- » Increasing vineyard efficiency

Our grape and wine research

Vineyard Longevity

3. Increasing commercial lifespan of NZ vineyards

» Control and new surveillance systems for terminal disease vectors

» Management of terminal vine diseases (leafroll virus, trunk disease…)

» Producing rootstocks that contribute to vine longevity

Our grape and wine research

Future Protection

4. Protect NZ's vineyards from future threats

- Semiochemical based systems for mealybug control
- New incursions
- Climate change
- Eco-verification of production systems
- Catastrophic event management

Our grape and wine research

Disease Management in Low Input Systems

5. Minimise the impact of seasonal diseases in low input systems

» Improved uptake of viticultural decision support systems

» New bunch rot disease management tools

» Biology and epidemiology of grapevine mildew diseases

» Genetic differences to botrytis susceptibility

Plant & Food RESEARCH
RANGAHAU AHUMĀRA KAI

The New Zealand Institute for Plant & Food Research Limited

damian.martin@plantandfood.co.nz

Appendix 2. Jerry Cooper

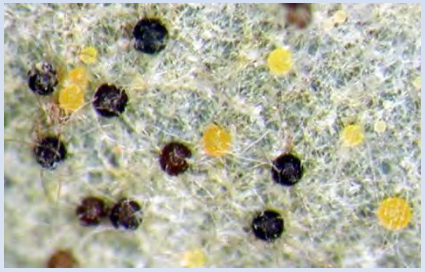
Grape PM Genetic Studies

Jerry Cooper
Peter Johnston
Duckchul Park

Landcare Research

Grape Powdery Mildew
Erysiphe necator

- Originates on wild grape relatives in USA
- Present in New Zealand over 100 years
- Only known in the asexual (and clonal) form ...
- ... until 2013 in Hawke's Bay (Peter Wood).



The sexual 'chasmothecia' noted for the first time

And associated with more severe disease symptoms

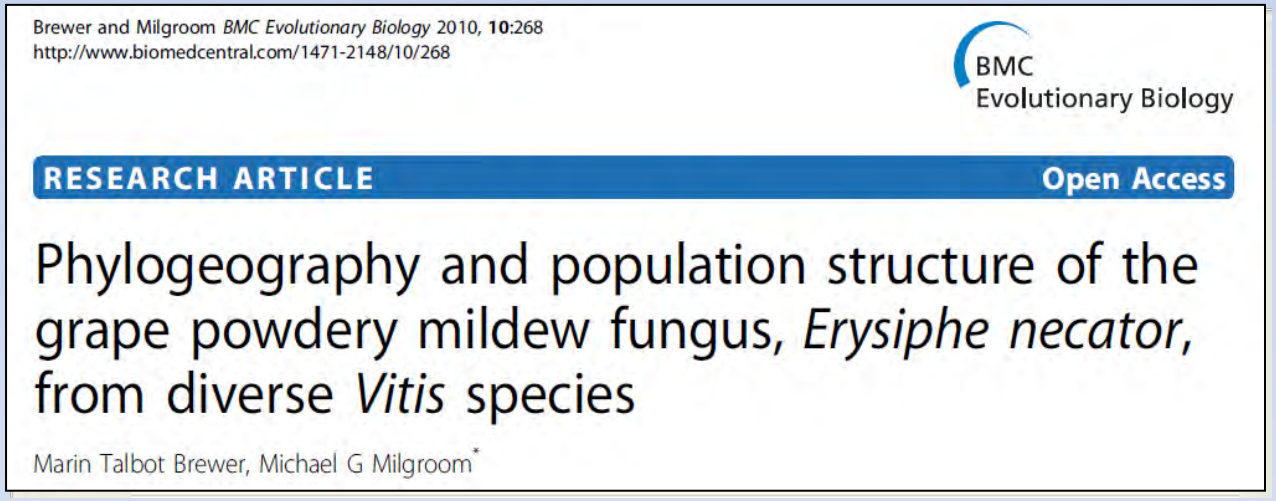
The Powdery Mildew Life Cycle Asexual

- **Asexual** spores (conidia) formed throughout growing season in huge numbers
- Continuous cycle of re-infection, growth, sporulation, dispersal
- Conidia generally do not survive over winter
- **Spring re-growth from resting infection in buds** appearing as white/grey ‘Flag Shoots’
- Clonal

The Powdery Mildew Life Cycle Sexual

- **Sexual** chasmothecia formed towards the end of the season
- **Survive over winter in litter, soil etc**
- **Spores released from chasmothecia in spring to re-infect**
- Requires compatible mating types

Genetic Characterisation
The Technique



Brewer and Milgroom *BMC Evolutionary Biology* 2010, **10**:268
http://www.biomedcentral.com/1471-2148/10/268

BMC Evolutionary Biology

RESEARCH ARTICLE Open Access

Phylogeography and population structure of the grape powdery mildew fungus, *Erysiphe necator*, from diverse *Vitis* species

Marin Talbot Brewer, Michael G Milgroom*

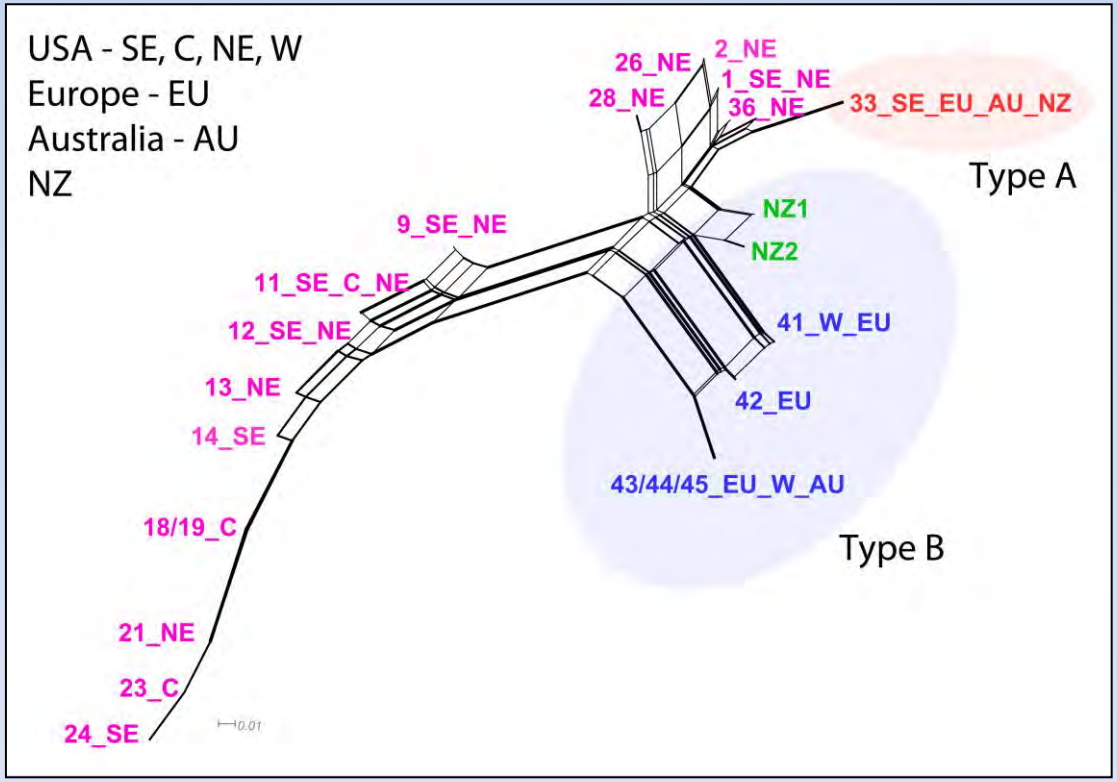
Brewer & Milgroom 2010

- Studied populations in US, Europe, Australia
- Identified 45 populations, most in US
- **Just 2 groups in Europe/Australia**
- Inferred groups equivalent to historical Types A & B
- **Type A – asexual, overwinters in Flag Shoots**
- **Type B – sexual, overwinter as Chasmothecia** (but also in Flag Shoots we now know)

Genetic Characterisation
The NZ Samples

- 37 samples from Vineyards in Auckland, Hawke's Bay, Gisborne, Nelson, Marlboro & Otago
- Some sampled 2014, all sampled 2015
- Berries with mostly asexual stage
- Berries and leaves from garden table grapes in Canterbury
- Collected various dates in period January to March
- Not easy to collect clean samples for good DNA!

Genetic Characterisation
Brewer & Millgroom Plus NZ data

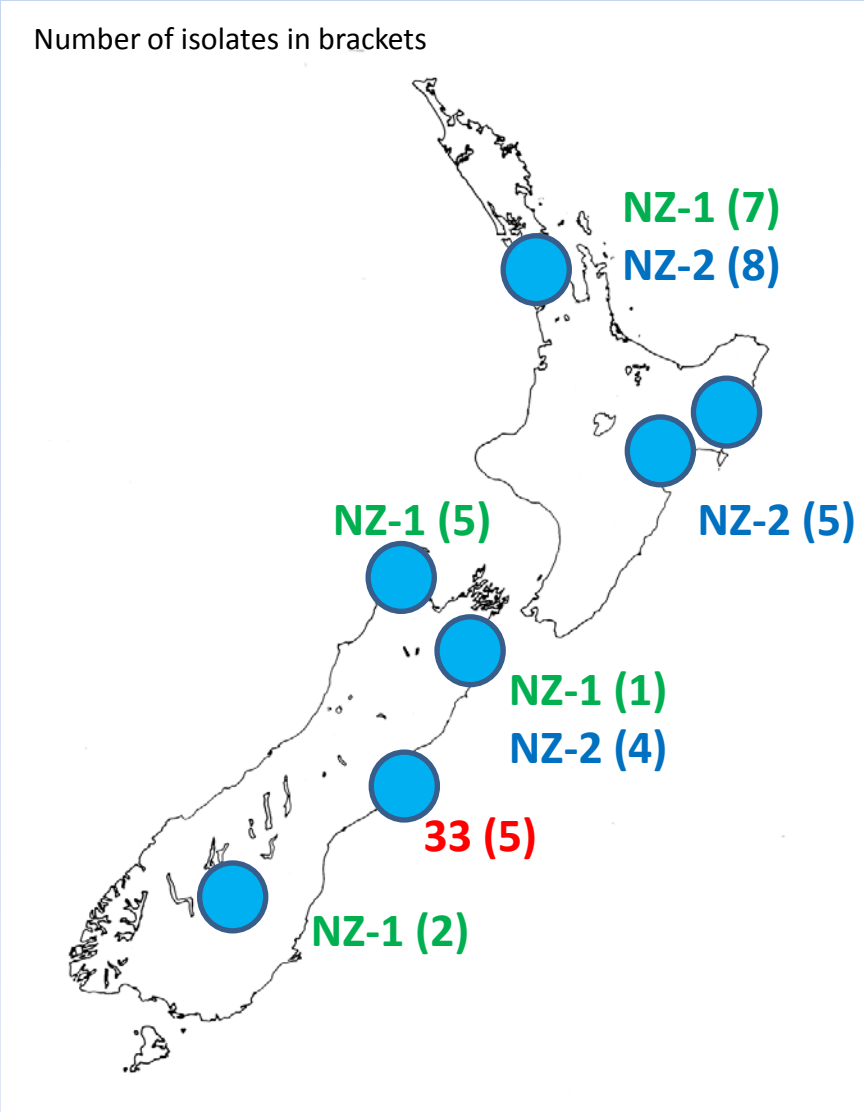


Population relationships

- NZ has both Types A + B
- Type A same as elsewhere
- Type B not the same as elsewhere
- We have two different B populations NZ1 & NZ2
- Only NZ2 associated with chasmothecia (requires confirmation)
- Only NZ2 associated with increased symptoms and management problems (for sure)

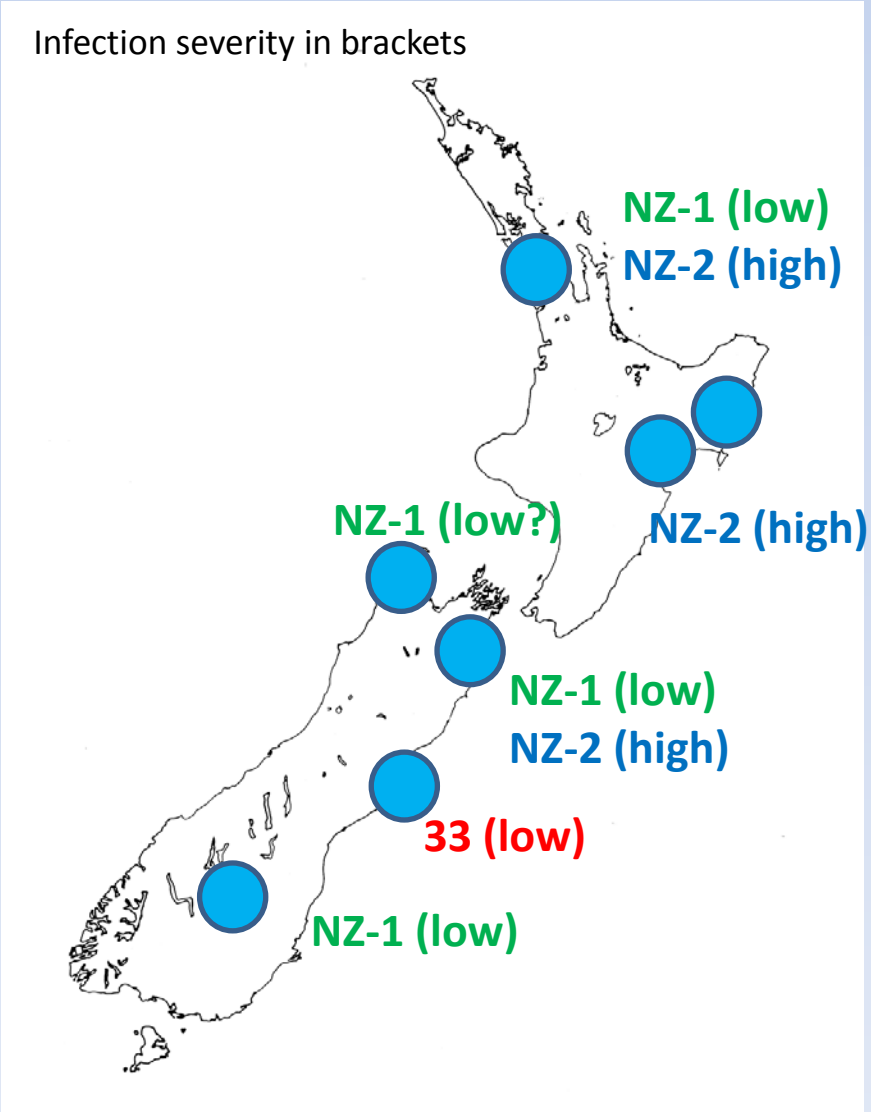
Type B- NZ1 – present in Auckland, Nelson, Otago
Type B- NZ2 – present in Auckland, Marlboro, Hawke's Bay, Gisborne
Type A - 33 – present in Christchurch (garden table grapes)

Preliminary data worth exploring



- Regional?
  - Sex only in north (currently)
  - Sex only associated with NZ2 (currently)
- Management?
  - Commercial vineyards versus backyards different. Just timing of samples?
- To resolve
  - Sample southern vineyards
  - Sample backyard vines in the north
  - Sample changes over entire season across the country

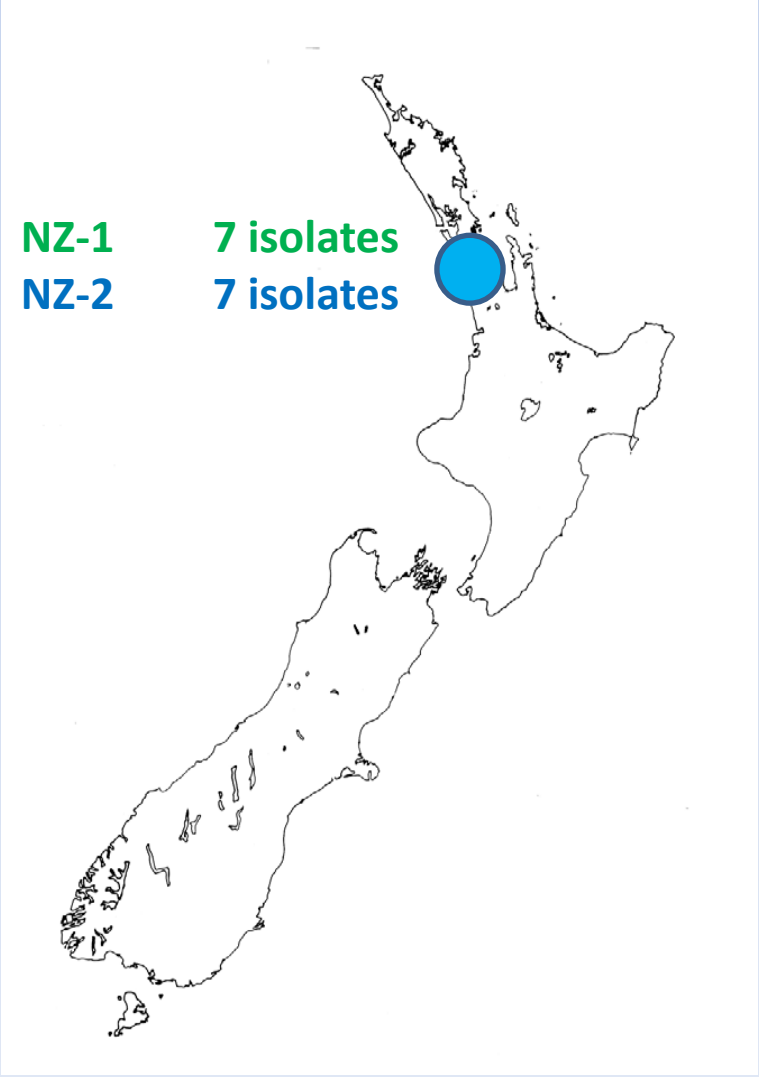
Preliminary data worth exploring



Disease severity

- Is this correlation real?
- Consequences for management and control?

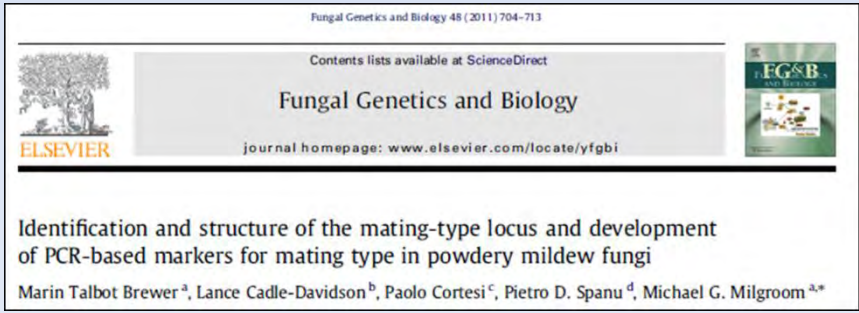
Preliminary data worth exploring



Ratio of mating types (think 'males' versus 'females')

Population	Mating type ratio	Chasmothecia
NZ-1	6:1	?
NZ-2	4:3	yes

- Stable recombining populations the ratio should be 1:1
  - Differences real? If yes, they are suggests two separate introductions at different times
- Does the NZ-1 population develop chasmothecia?
  - If yes, then we may have two sexual strains with potentially different characteristics and distribution
- Is the ratio changing with time and location?
  - If yes, then can (back) track the origin and spread


Fungal Genetics and Biology 48 (2011) 704–713

Contents lists available at ScienceDirect

Fungal Genetics and Biology

journal homepage: www.elsevier.com/locate/yfgbi

ELSEVIER

Identification and structure of the mating-type locus and development of PCR-based markers for mating type in powdery mildew fungi

Marin Talbot Brewer [a], Lance Cadle-Davidson [b], Paolo Cortesi [c], Pietro D. Spanu [d], Michael G. Milgroom [a,*]

Genetic Information/Characterisation France

Eur J Plant Pathol (2009) 123:61–70

Spatio-temporal distribution of *Erysiphe necator* genetic groups and their relationship with disease levels in vineyards

Josselin Montarry · Philippe Cartolaro · Sylvie Richard-Cervera · François Delmotte

This key study showed

- Flag shoots may harbour A & B
- Ratio varies between vineyards
- At end of season all vineyards have only Type B
- **Vineyards with greatest early Type B infection show greatest late season disease level**

In New Zealand ...

- Flag shoot populations unsampled
- **Correlation between early season population structure and disease untested**
  - **and our Type B is different to everywhere else**

Can genetics inform management?

- All results very preliminary
  - Need many more samples
  - Collecting samples technically challenging
- Despite this, worth exploring
  - Disease prediction
    - Are sexual NZ-1 versus NZ-2 disease level differences real?
    - Can flag shoot sexual/asexual ratios predict disease severity?
    - Are there regional differences in disease risk?
  - Will help inform whether adoption of a response strategy based on overseas models is appropriate
    - NZ-1 and NZ-2 populations differ from all overseas populations sampled

Acknowledgements

- Peter Wood
- Chris Henry
- Sioban Harnett
- and everybody who sent me samples from around the country

END

Appendix 3. Peter Wood

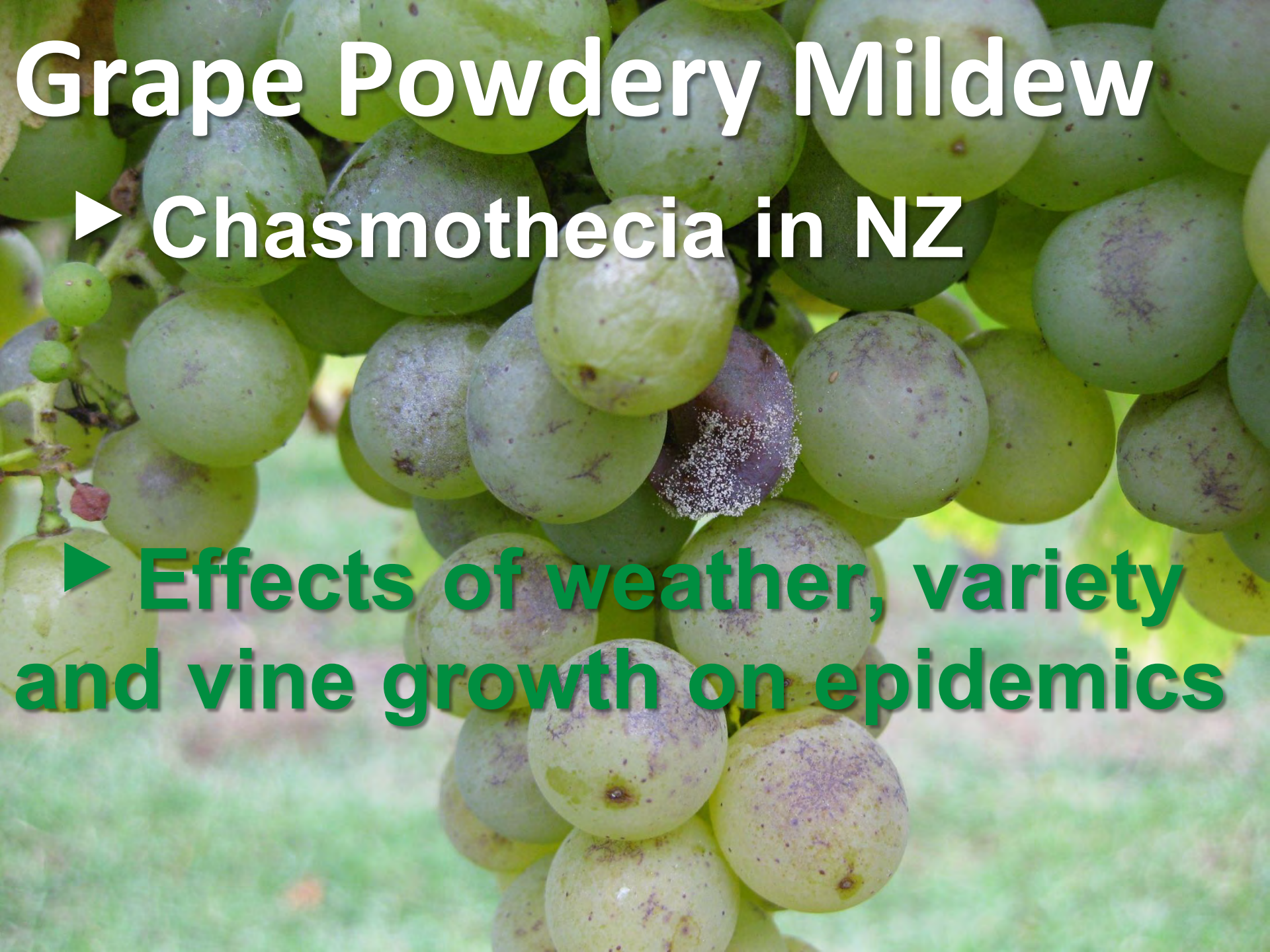
Grape Powdery Mildew

- Chasmothecia in NZ
- Effects of weather, variety and vine growth on epidemics

Peter Wood and Rob Beresford
Plant and Food Research, Hawke's Bay and Auckland

Grape Powdery Mildew

- Chasmothecia in NZ
- Effects of weather, variety and vine growth on epidemics



Powdery mildew sexual stage (SS) discovery

27 Jan 2014 in HB

Feb. survey - widely found in Gisborne & H Bay.

France - PM introduced1847, SS confirmed **1892 (45y)**
Australia - PM intro.1866, SS confirmed **1985 (119y)**
NZ - PM intro.1870's, SS confirmed **2014 (ca.144y)**

Genetically distinct groups (A & B)

- **In southern France - Group A** (flagshoot) isolates disappear during the course of the epidemic

- **Group B** isolates active during the entire epidemic and produce chasmothecia (cleistothecia)

Genetically distinct groups (A & B)

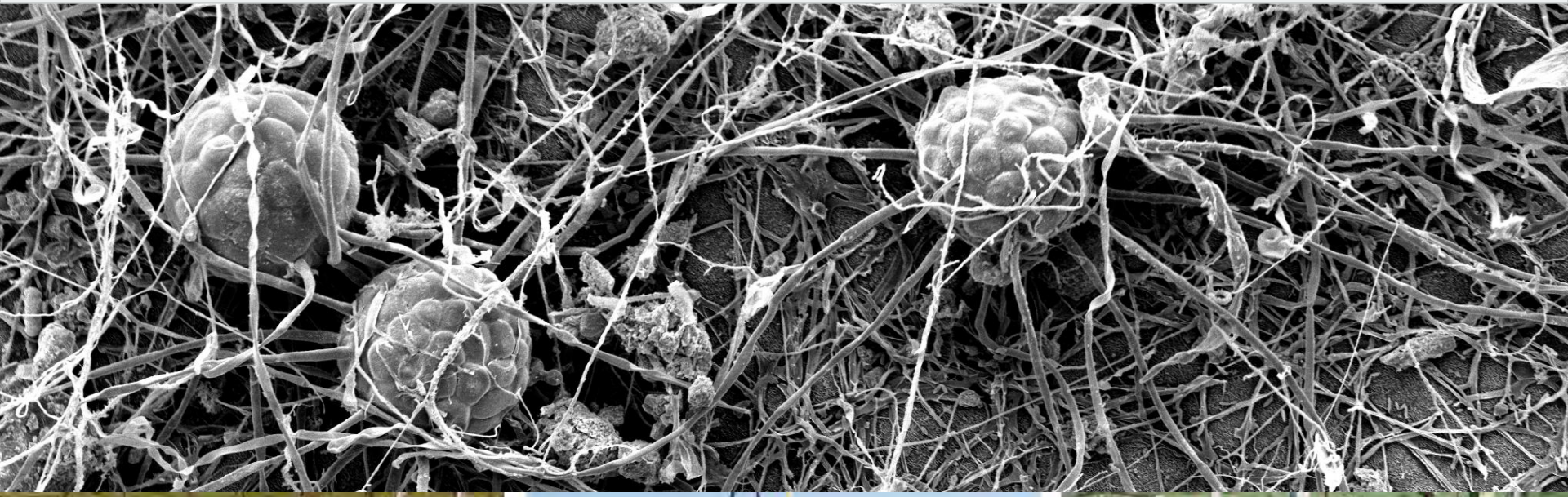
- In France, strong relationship between PM disease severity and genetic composition..

Implications...greater crop damage when the epidemic was initiated by **Group B** (sexual) isolates.

Chasmothecia

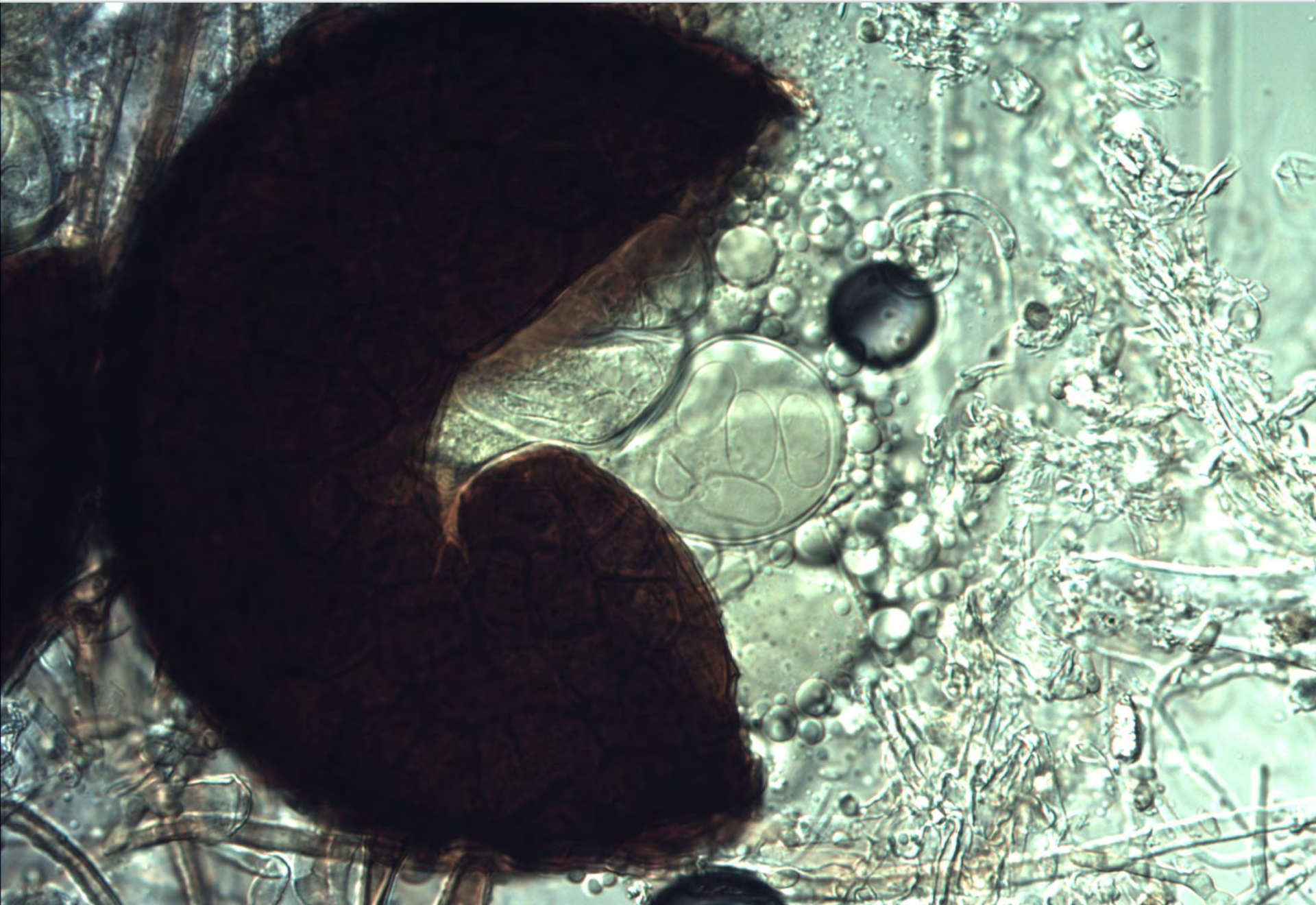
– production peaks mid-late season

– washed down into bark by autumn rains

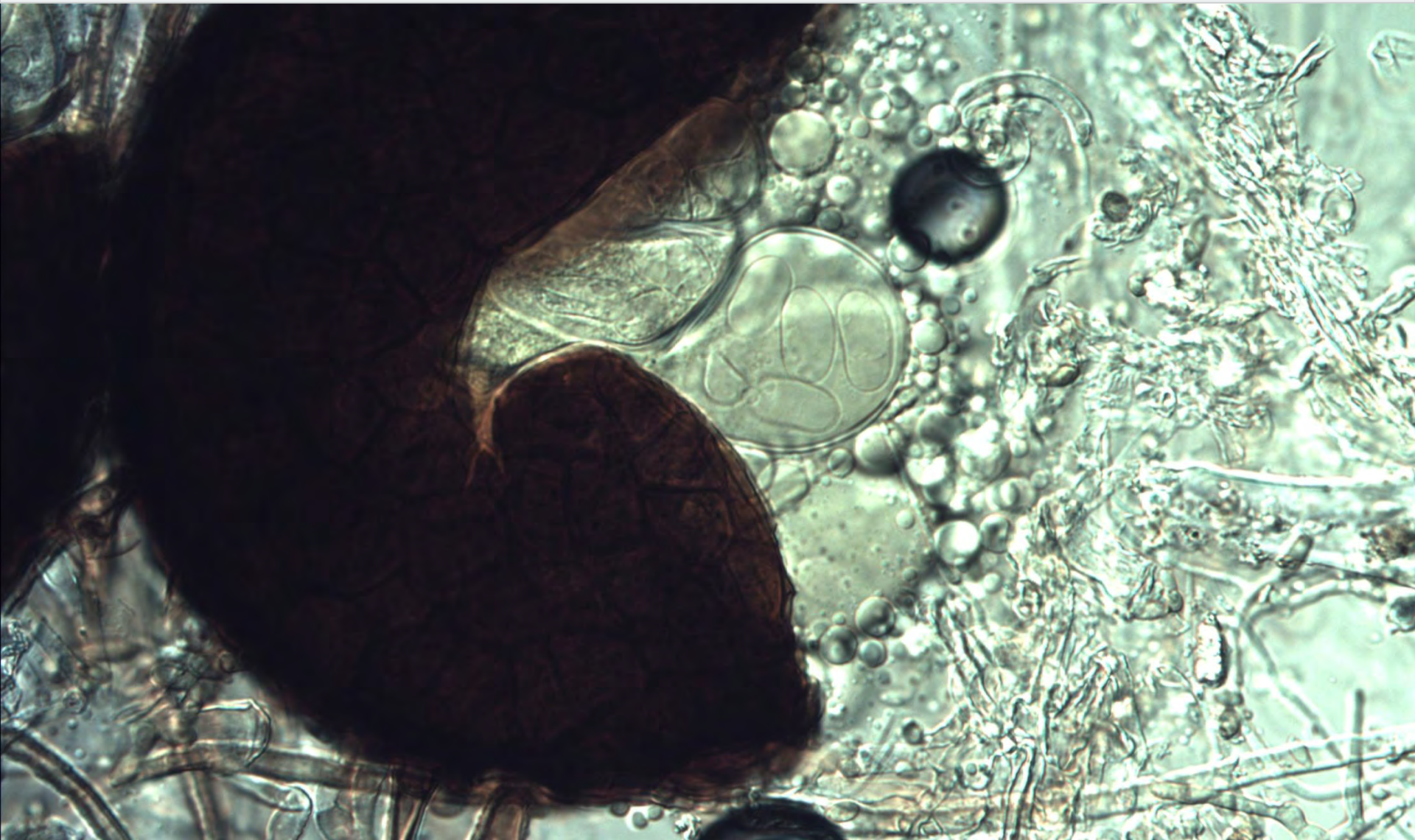


Chasmothecia – overwinter best in bark

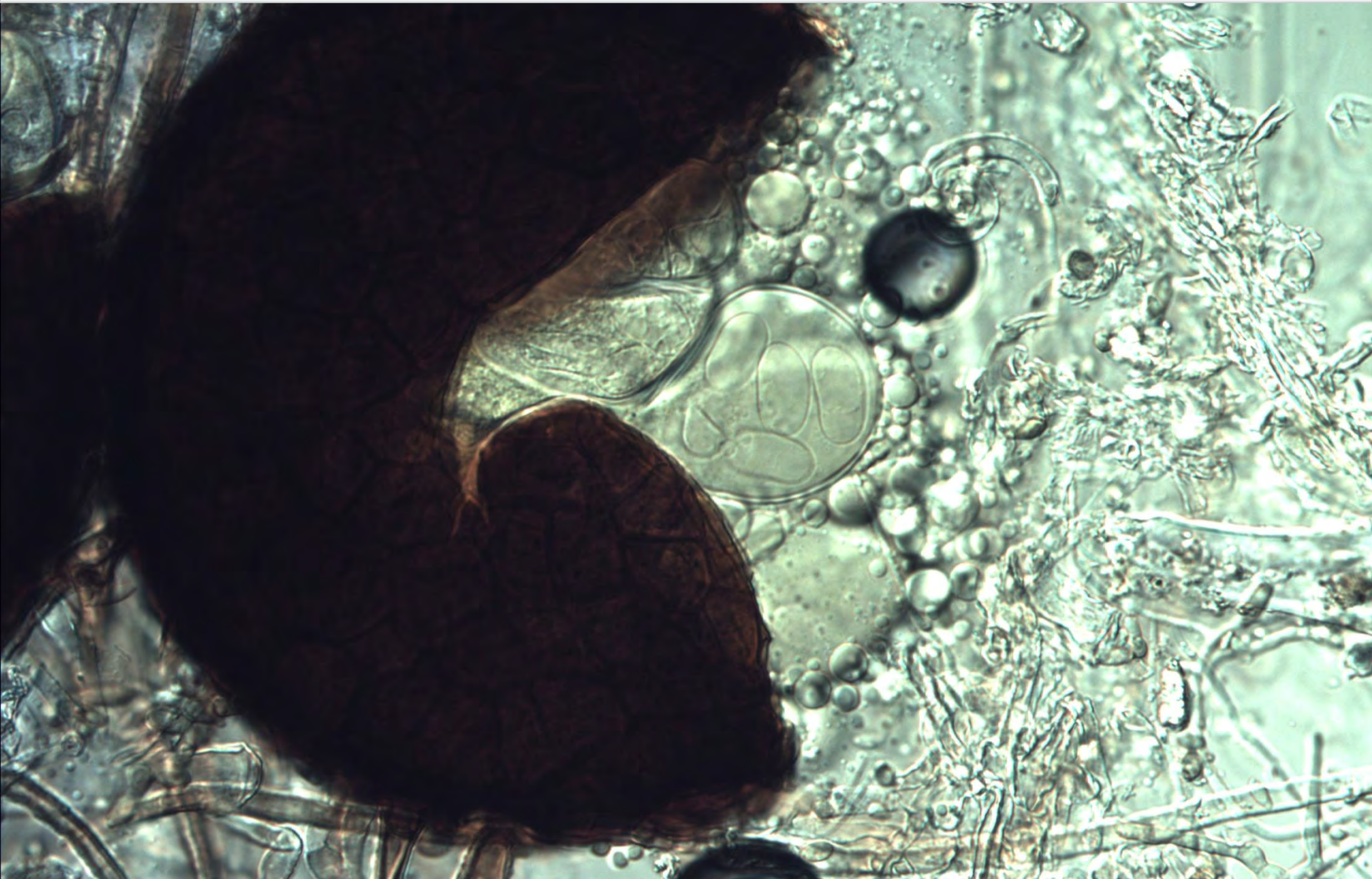
Ascospore release in NZ - we don't know



Ascospore release – usually between bud burst & bloom only during or immediately following rains of more than 2.5mm while temperature >10˚C.



Ascospore release – can be modelled and warning systems utilised to schedule fungicides.

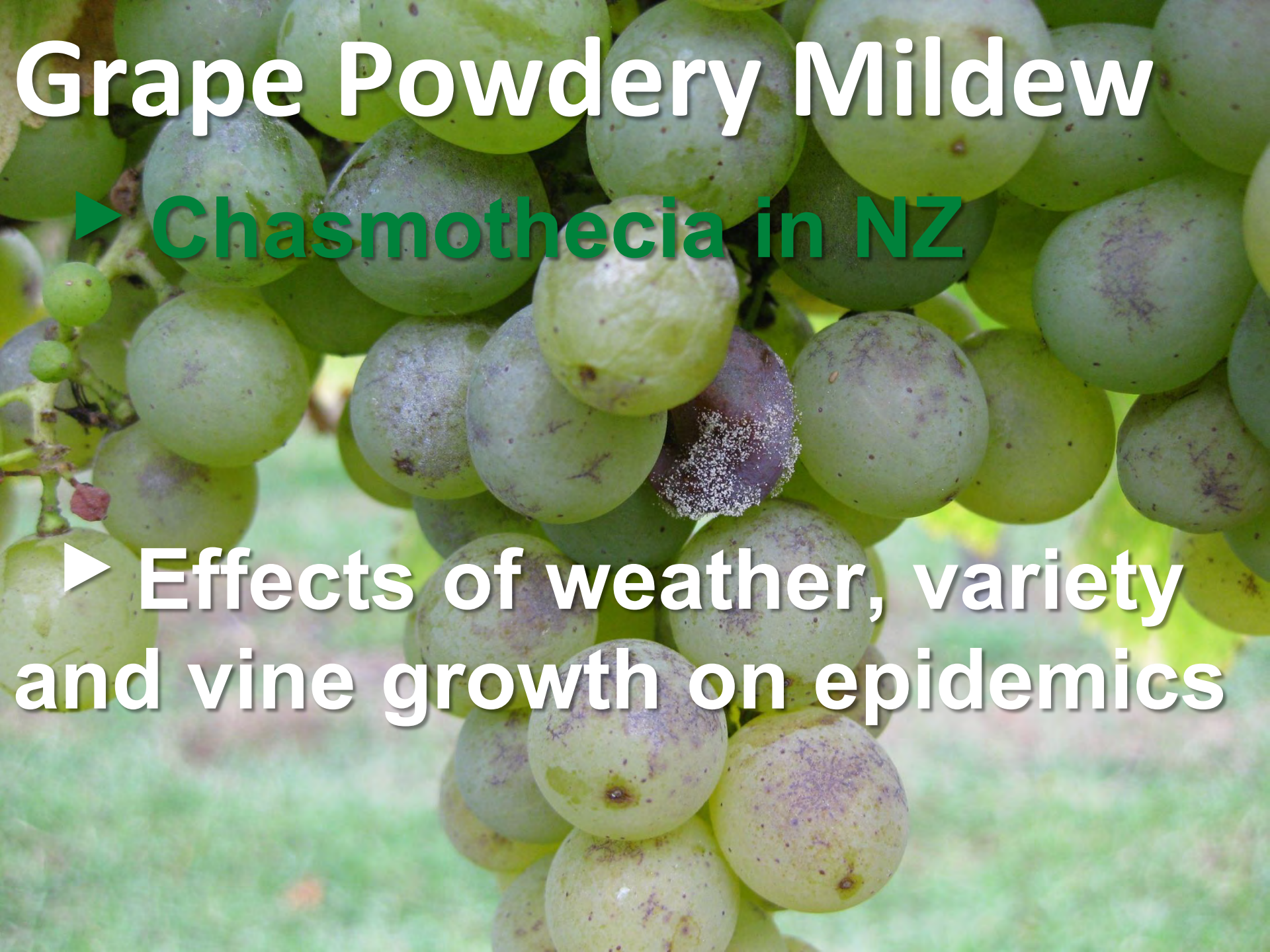


Ascospores summary – may provide an additional boost of inoculum in the spring

- Genetic recombination via the sexual stage will generate fungicide resistant strains more rapidly
- Chasmothecia have been found in all NZ's major wine regions
- How can we monitor the degree to which chasmothecia contribute to early-season inoculum?
- How can be target chasmothecia to knock them out?

Grape Powdery Mildew

- Chasmothecia in NZ
- Effects of weather, variety and vine growth on epidemics



Powdery mildew – Environment

- **Environment ... What's required? Warm, dry.**

- Powdery mildew is mostly **inoculum driven**, however ...

PM enhanced by

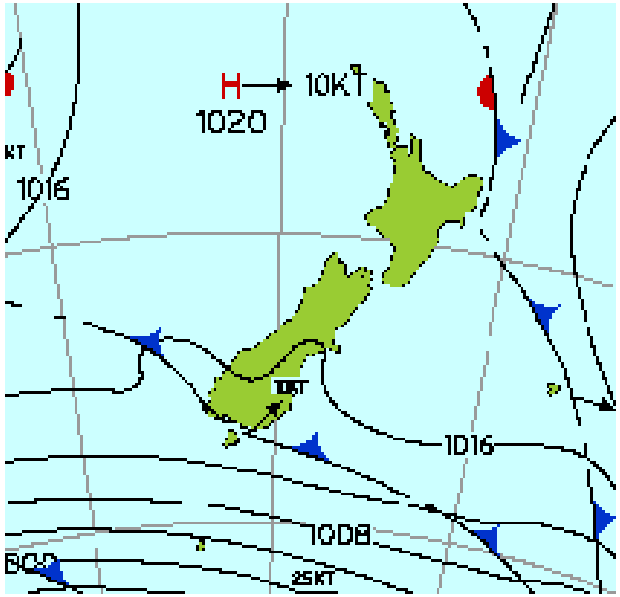
› **Warm**; 20-28˚C optimum PM generation 18d=12˚C v 6d=24˚C.
› **High humidity**; double PM severity at 80% RH cf. 40% RH.
› **Low light**; UV - spore killer (not pigmented, is an ectoparasite).

PM retarded by

< **Rainfall detrimental** – damages conidia and mycelium.
< **Cold detrimental** - 2h at 2˚C kills.

Effects of weather on powdery mildew

- Dry warm summer weather is perfect for powdery mildew development, although UV light can kill the spores
- Epidemics are inhibited in rainy seasons
- In NZ, hot summer temperatures are unlikely to kill infection (c.f. California)



- Cold spring temperatures reduce leaf susceptibility
- Can weather risk models help time fungicides, or do susceptibility and inoculum drive the epidemics?
- How important have the last three drier seasons been for the current powdery mildew problem?

Powdery mildew – The Grapevine

•Host… Why it matters?

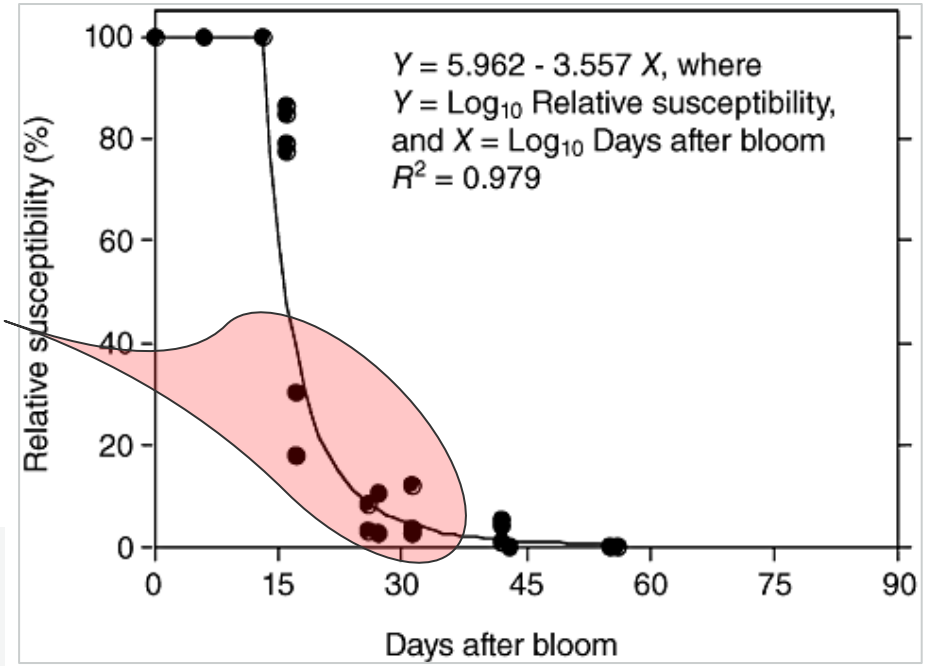
- All green parts susceptible.
- All classical varieties susceptible.
- Low UV increases leaf susceptibility.
- Low temp reduces susceptibility.
- Crop very susceptible pre flowering to 3-5 wks post fruit set.
- Adverse effects on yield and wine quality
- Increased susceptibility to bunch rots.

Developmental changes in host resistance

Leaves - peak susceptibility when half expanded, but never immune to infection.

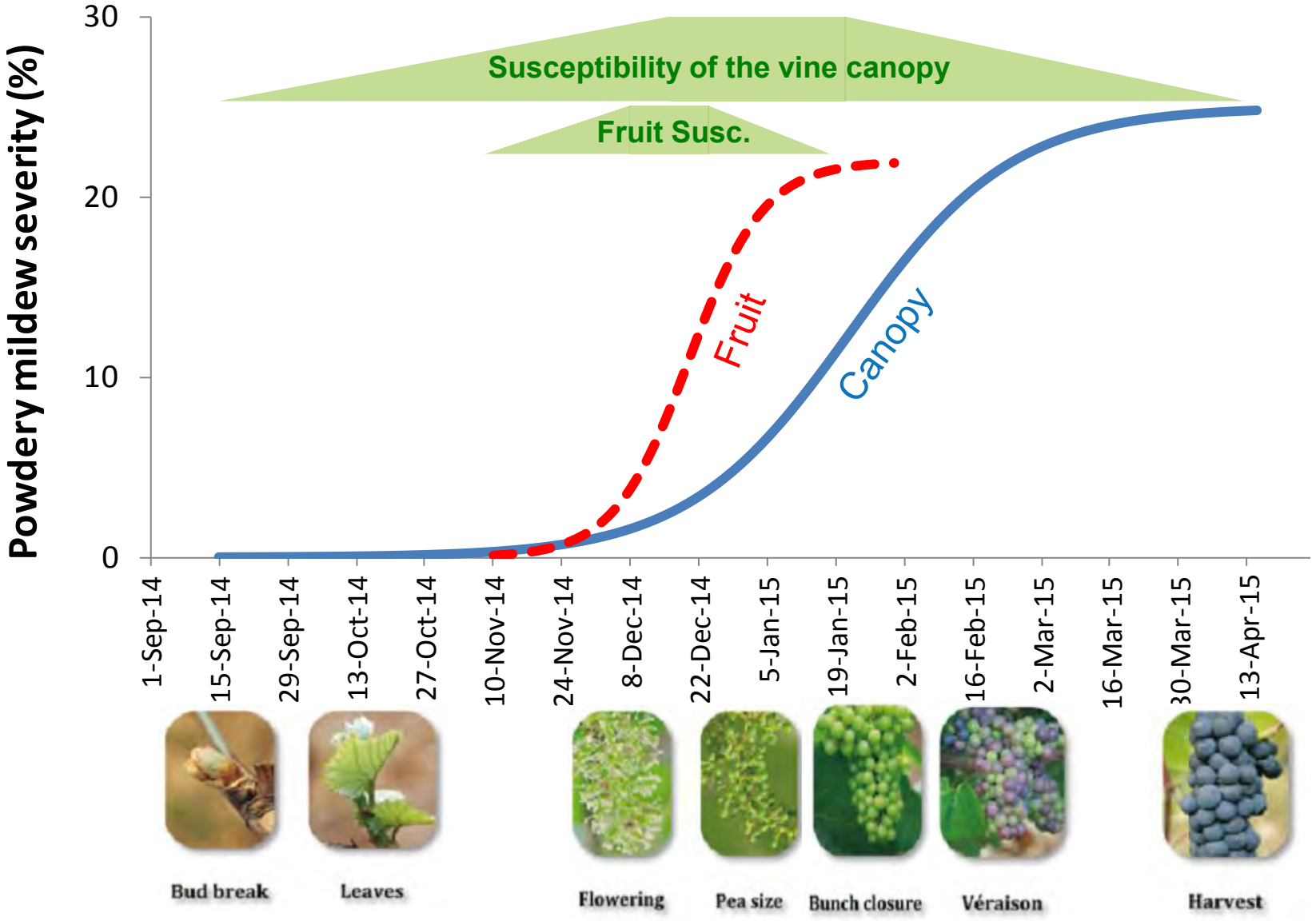
Fruit - susceptibility is relatively brief.
Berries highly susceptible for the first 2 weeks after set.

Diffuse PM develops on berries as they transition to an ontogenically resistant state.

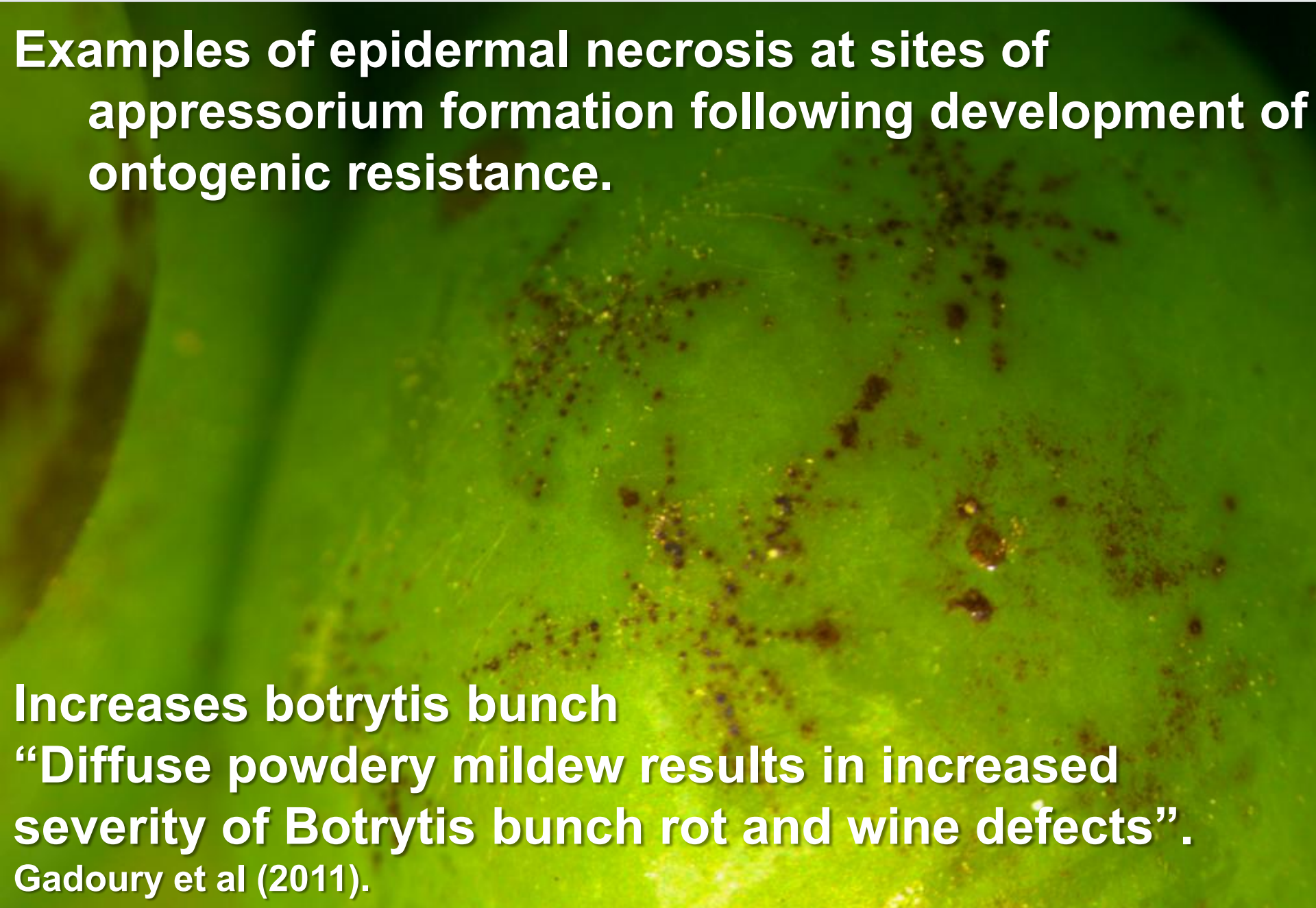


GADOURY, D. M., CADLE-DAVIDSON, L., WILCOX, W. F., DRY, I. B., SEEM, R. C. and MILGROOM, M. G. (2012), Grapevine powdery mildew (*Erysiphe necator*): a fascinating system for the study of the biology, ecology and epidemiology of an obligate biotroph. Molecular Plant Pathology, 13: 1–16. doi: 10.1111/j.1364-3703.2011.00728.x

Fruit susceptibility - peaks in a 2-3 week window from start of flowering. Fruit have their own epidemic.



Diffuse Powdery Mildew



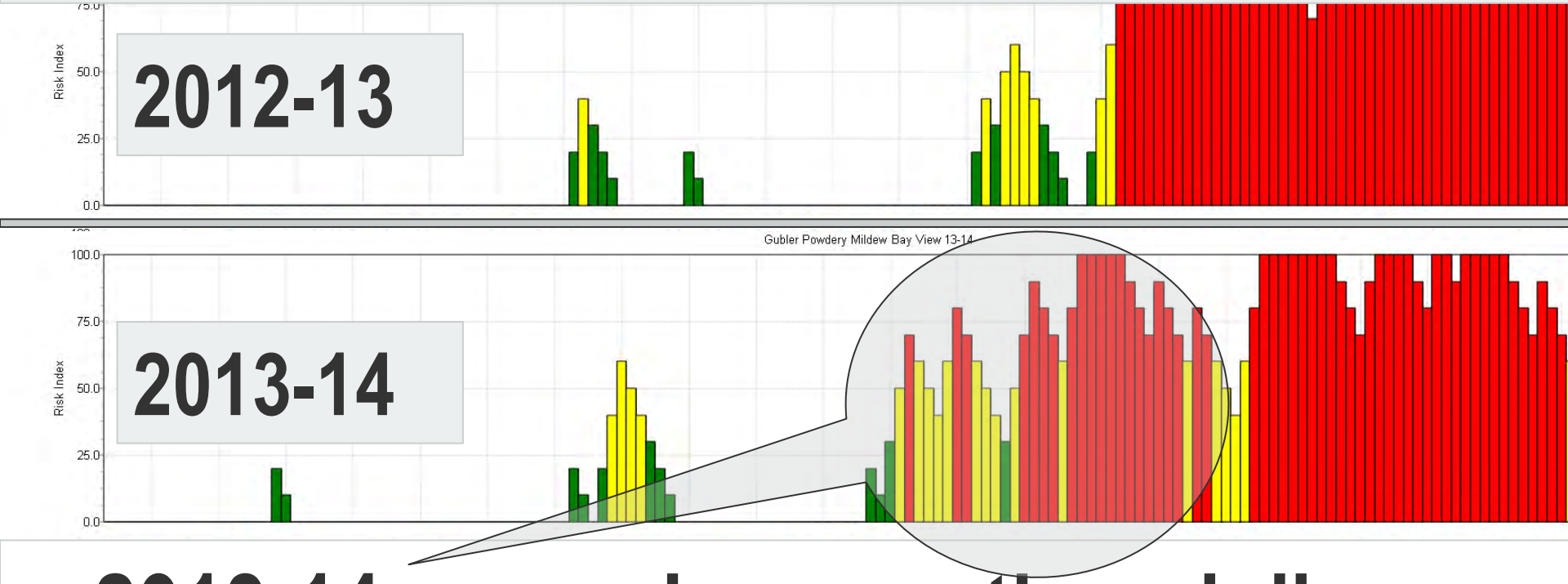
Examples of epidermal necrosis at sites of appressorium formation following development of ontogenic resistance.

Increases botrytis bunch

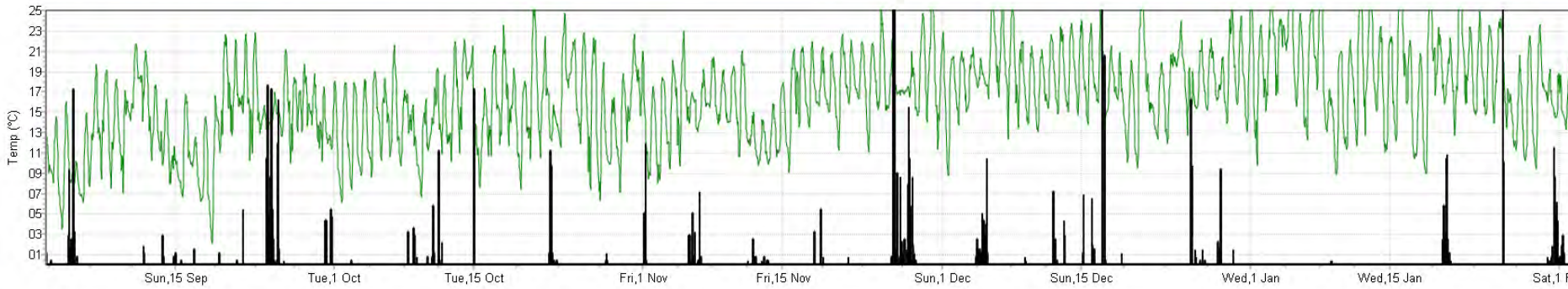
“Diffuse powdery mildew results in increased severity of Botrytis bunch rot and wine defects”.

Gadoury et al (2011).

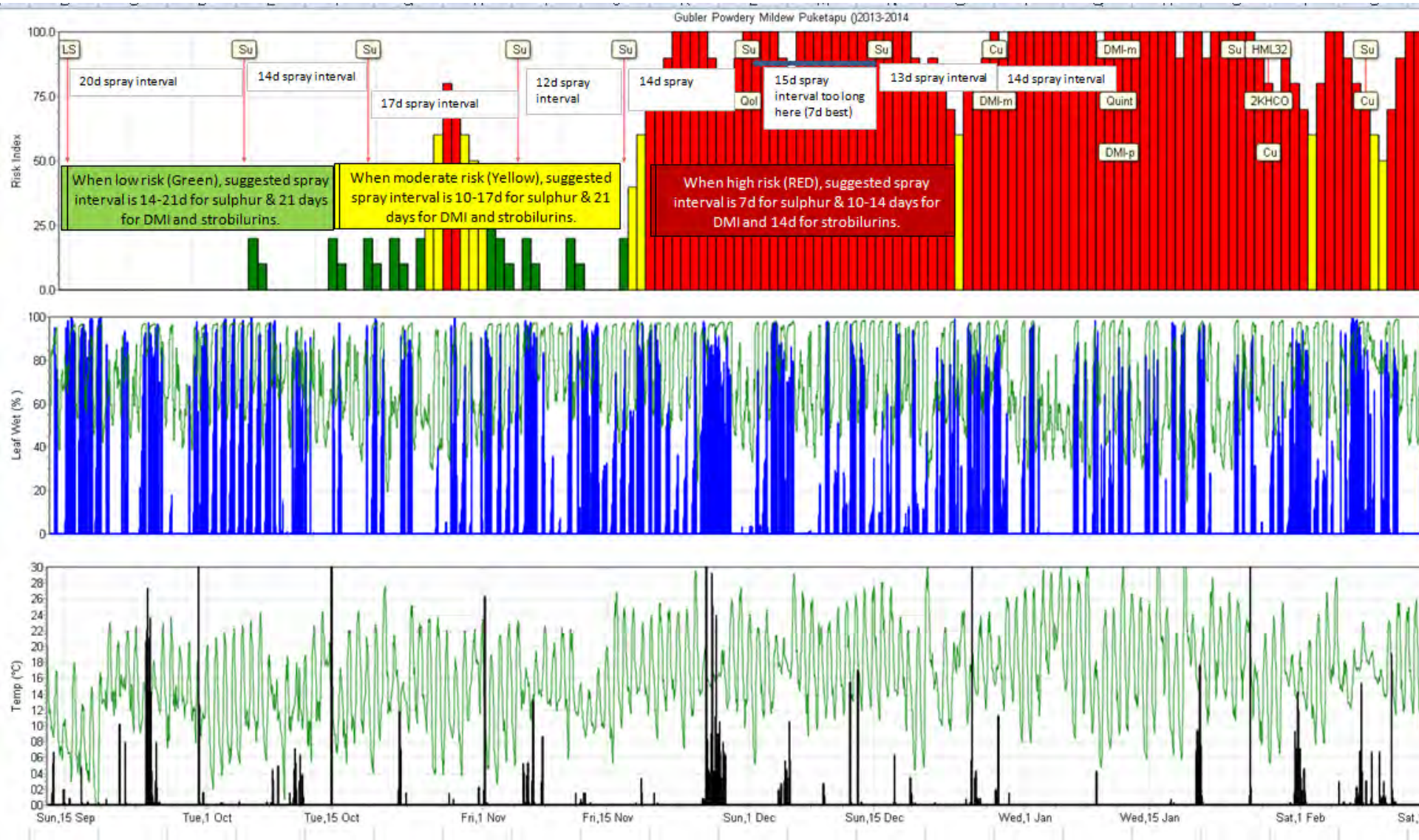
Warmer spring 2013 – more disease risk



2013-14 more vine growth and disease risk at flowering and soon after



Hawke's Bay grower - crop lost to PM in 2014
Spray timing potentially at fault



PM disease risk increases at flowering

Monitor spray deposition at flowering - important as fruit zone becomes congested.

Flowering = Perfect storm - Increasing; temperatures humidity & shade & inoculum & susceptible tissues.

The timing of fungicide applications

The timing of fungicide applications may be based on;

1. **Calendar** days,
2. **Phenology** or
3. **Weather-driven advisory models**, the most widely deployed is the Gubler

Unexpectedly slow development of PM during the first month after budbreak.

Pathogen - favoured by warm, 20-28˚C optimum

Host - 2–4 ˚C for 2–8 h increases resistance to infection.

Unsprayed Hawke's Bay Chardonnay 2014-15
Was Powdery Mildew severe?

Peter Wood and Rob Beresford
Plant and Food Research, Hawke's Bay and Auckland

Plant & Food RESEARCH
RANGAHAU AHUMĀRA KAI

Appendix 4.Trevor Lupton

Gisborne Powdery Mildew Situation 2013, 2014 & 2015

Spray Diary Analysis 2013 & 2014

Paired:

- Good vs poor PM outcome
- Sprayer type
- Locality
- Variety (chardonnay)
- Training System

Spray Diary Analysis

- **Looked at:**
  - Product and Rate per hectare
  - Water rate & adjuvants
  - Application Interval
  - Kilos of Sulphur pre flower

Spray Diary Analysis: Vineyard A vs B

Vineyard	A	B
Flowering to Bunch Closure		
Applications	6	8
Interval	6-13 Days	6-12 Days
Water rate per hectare	330 litres + DuWett	500 litres
Product rate per hectare	ok	ok

No apparent differences between good & poor PM outcomes

Spray Diary analysis does not show:

- PM carry over from previous season
- Quality of sprayer coverage

A Trend Began to Emerge: Flowering to Bunch Closure Fungicide Use

13 blocks with good PM outcome:

- 6 used 0 DMI
- 7 used 1 DMI

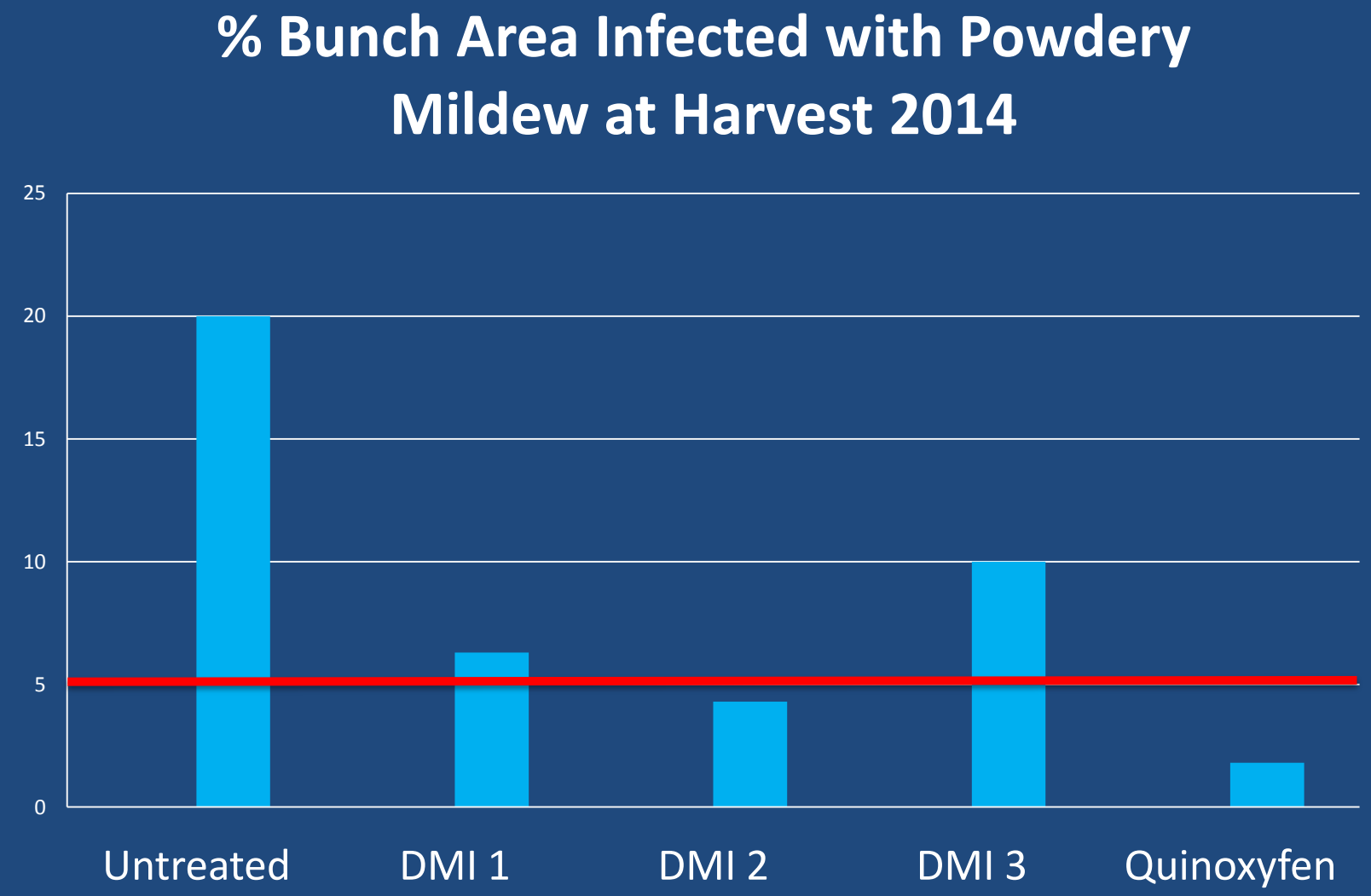
17 blocks with poor PM outcome:

- 6 used 1 DMI
- 11 used 2 DMIs
  - Tended to also use more DMI post bunch closure

Grochem PM Trial Hawkes Bay 2013-14 Chardonnay

- **Treatments:**
- Untreated Control
- 3 different DMIs
- Quinoxyfen
- **Applications started at early flowering and were repeated 3 times at 17-23 day intervals**

Grochem PM Trial Hawkes Bay 2013-14



Gisborne Spray Diaries with Poor PM Outcomes 2013 & Improved 2014

- 3 vineyards in this group:
- Flowering to Bunch Closure Fungicide Use

	2013	2014	2014 Changed to
Vineyard 1	2 DMI (+1 late)	0	Cabrio, 2x Talendo, Quintec (5 Jan)
Vineyard 2	2 DMI (+1 late)	0	2x Talendo
Vineyard 3	1 DMI (+3 late)	1 DMI (+1 late)	Talendo, Quintec (22 Dec)

Powdery Mildew Best Practise: Does the industry have the answers?

Chasmothecia:

- how important are they as an over-wintering inoculum source?

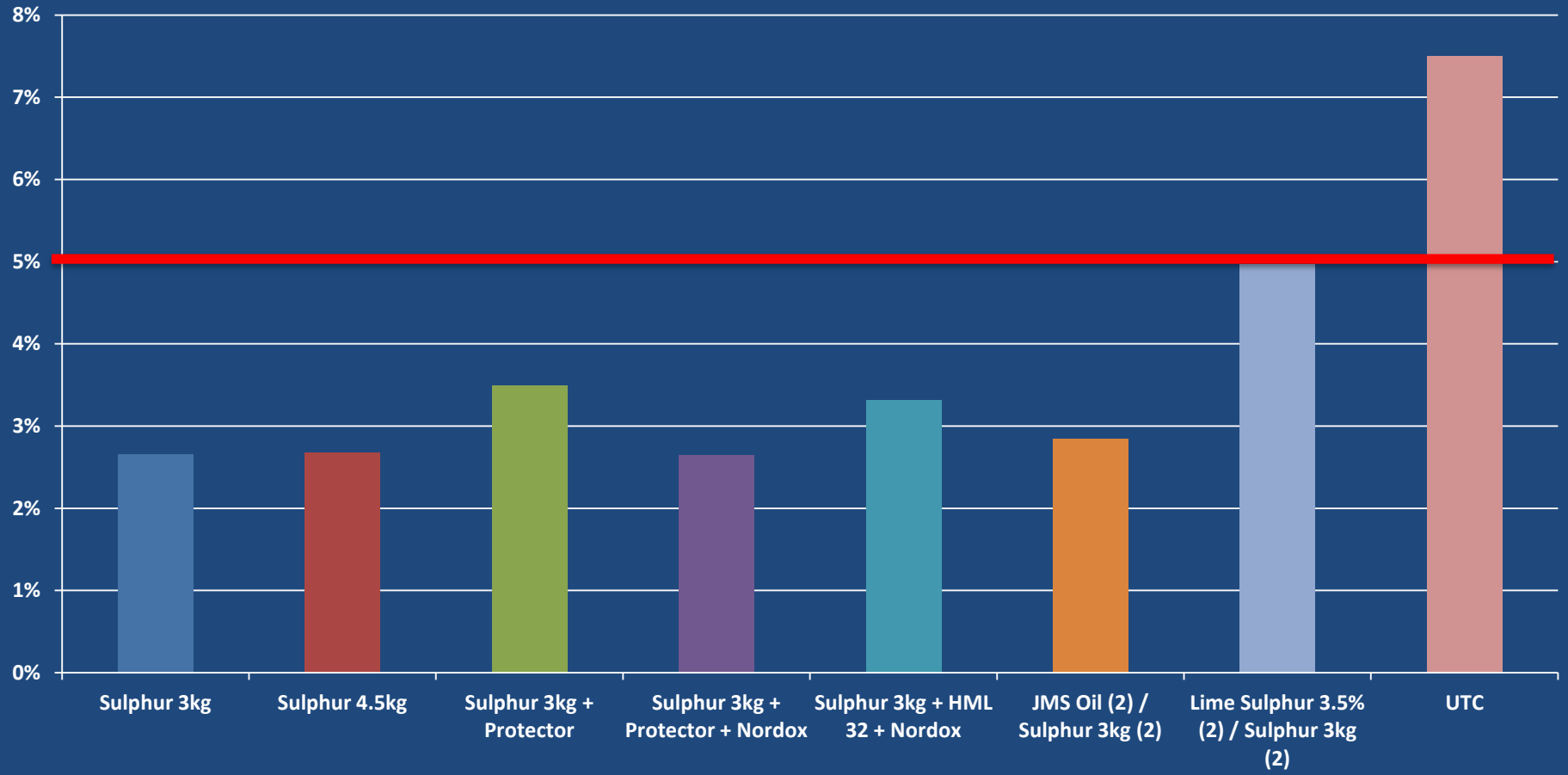
Fungicide efficacy:

- how effective are our fungicides?
- How do new fungicides compare?
- How do growers access information?

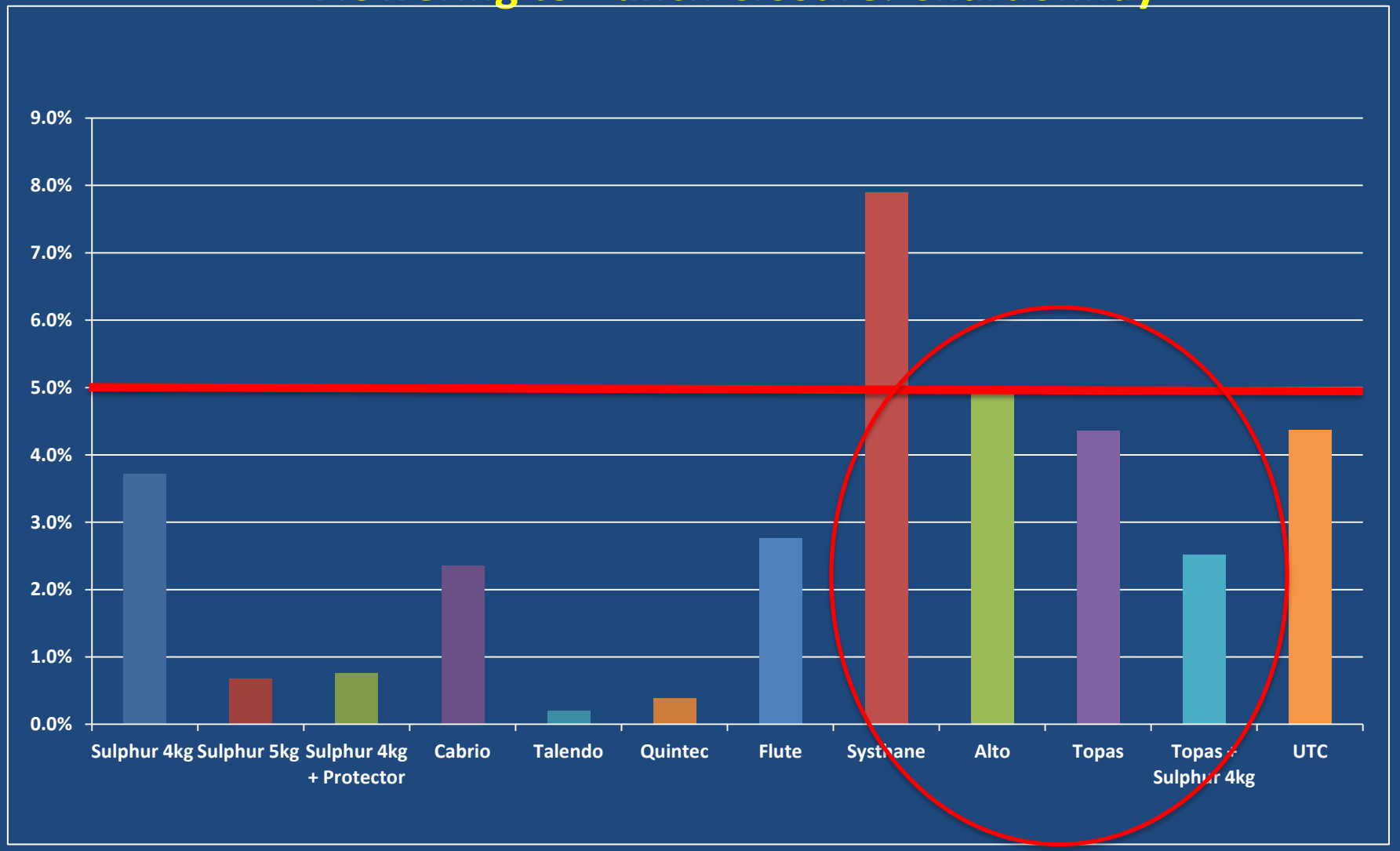
Developing Powdery Mildew Best Practise: Trials 2014-15

- Lime sulphur late dormant (Gs only)
- **Fungicide Options: 2 "windows"**
  - Budburst to Flowering:
  - Flowering to Pre Bunch Closure
- Grower applies powdery mildew fungicides before and after trial windows
- Trials in Gisborne & Marlborough

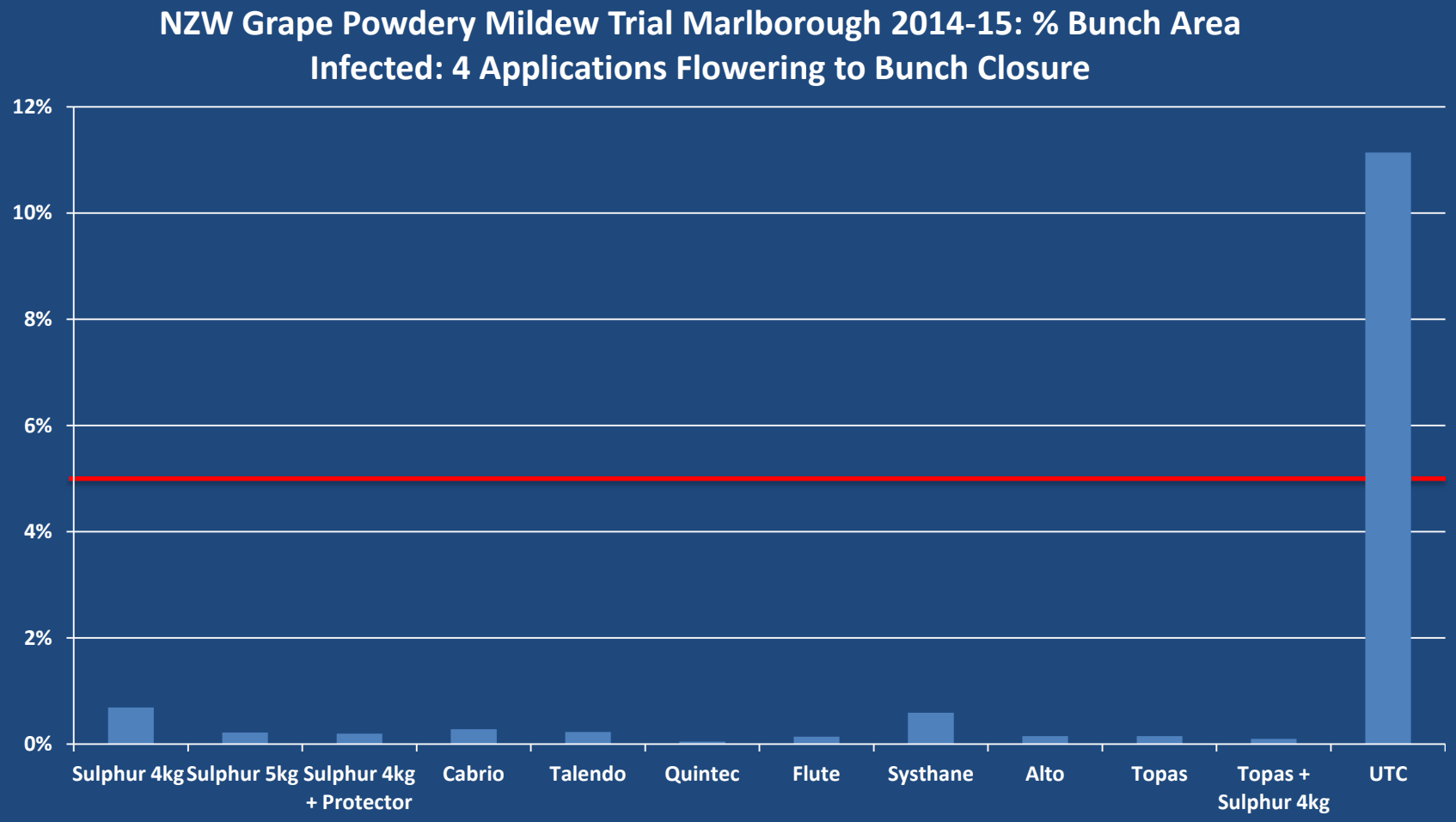
NZ Winegrowers Powdery Mildew Trial Gisborne 2014-15: % Bunch Area Infected Pre Harvest: Bud Burst to Flowering: 4 Applications at 14 Day Intervals: Chardonnay



NZ Winegrowers Powdery Mildew Trial Gisborne 2014-15: % Bunch Area Infected Pre Harvest: 3 Applications at 14 Days Flowering to Bunch Closure: Chardonnay



NZ Winegrowers Powdery Mildew Trial Blenheim 2014-15: % Bunch Area Infected Pre Harvest: 3 Applications at 14 Days Flowering to Bunch Closure: Sauvignon blanc



Grower Case Studies

Feb 2014:

- 2 Gisborne Vineyards: crop rejected or 20%-50% of fruit cut out pre harvest
- % area of bunch infected ranged 20%-50%

Feb 2015:

- % area of bunch infected ranged 0.4% to 2.3%

Grower Case Studies

Key Changes:

1. Sprayer setup and coverage optimised
2. No DMIs used
3. Mix of protectant and eradicant fungicides
4. Some changes to canopy management

Grower Case Studies

- **Lime sulphur: $120/ha.**
- **Lime Sulphur late dormant: % bunch area with PM pre harvest**

	Lime Sulphur	UTC
Vineyard 1	1.8%	2.8%
Vineyard 2	0.5%	0.3%

Eradicants

Oil: Immediate kill

But coverage is critical

Improving Coverage

Surround: note drip points

Surround + DuWett

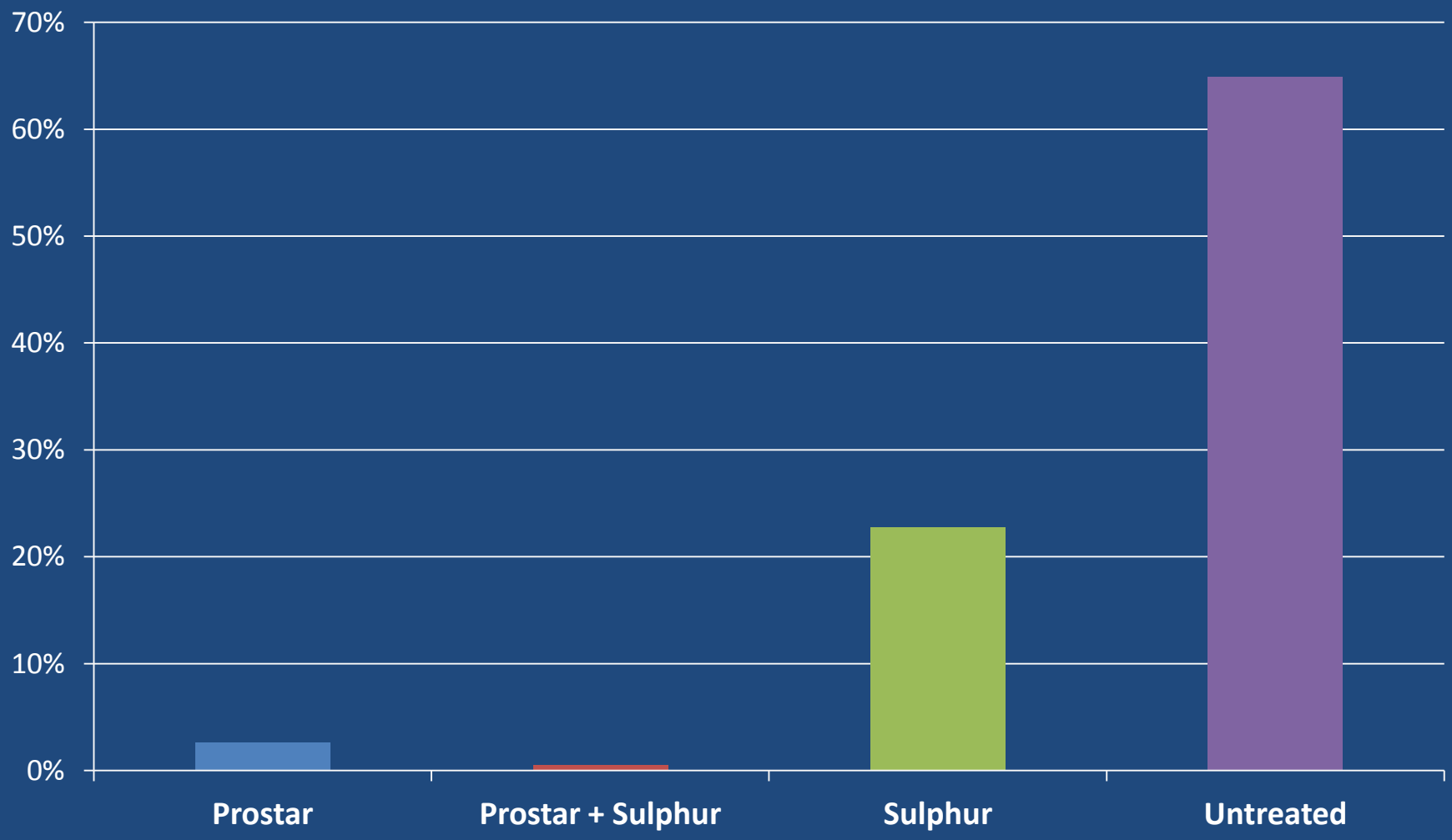
Surround for Sprayer Coverage Assessment

Surround

Resistance Management

- Eradicants need a protectant fungicide to extend cover
- If powdery levels are high – should be using durable protectants (sulphur), not single site fungicides
- Should we be mixing sulphur with single site fungicides?

Zelam Trials 2005-2007 Taranaki: % Bunch Area Infected (ex NZ Plant Protection Soc. Poster)



Appendix 5. Kirstin Wurms

The New Zealand Institute for Plant & Food Research Limited

The Role of Natural Products & Biologicals in Powdery Mildew Control Programmes

Kirstin Wurms, Annette Ah Chee, Peter Wood, Phil Elmer & Claire Hall

Acknowledgements

Funding for the Plant & Food Research (PFR) natural products research programme is greatly acknowledged from:

- NZ Winegrowers
- Fonterra
- BotryZen 2010 Ltd
- PFR

Presentation Overview

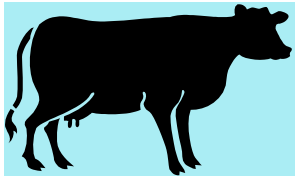
- Advantages & disadvantages of Natural Products (NPs) for crop protection
- Commercially available NPs for grape powdery mildew (PM) control
- NP development process
- PFR NP research programme incl. efficacy & mode of action data
- Best practice for NPs
- Conclusions & Recommendations

Global Drivers for Alternatives to Synthetic Pesticides:

- Increasing market requirements for residue-free food
- Withdrawal of pesticides from the market
- Pesticide resistance
- Continued & sustained growth of organics

Advantages of Natural Products (NPs)

- Ease of product registration e.g. dairy products considered non-toxic to humans
- Safe for the environment
- Short withholding period
- Suitable for both organic and conventional growers (extended market size)
- Appear to have multiple modes of action (less risk of resistance dvpt)
- May offer eradicant activity



Disadvantages of NPs

- Handling problems/formulation issues
- Phytotoxicity
- Spoilage/smell
- Poor durability &/or inconsistent control
- Blockage of spray equipment
- Lack of a USP
- Growth of non-target organisms e.g. sooty mould

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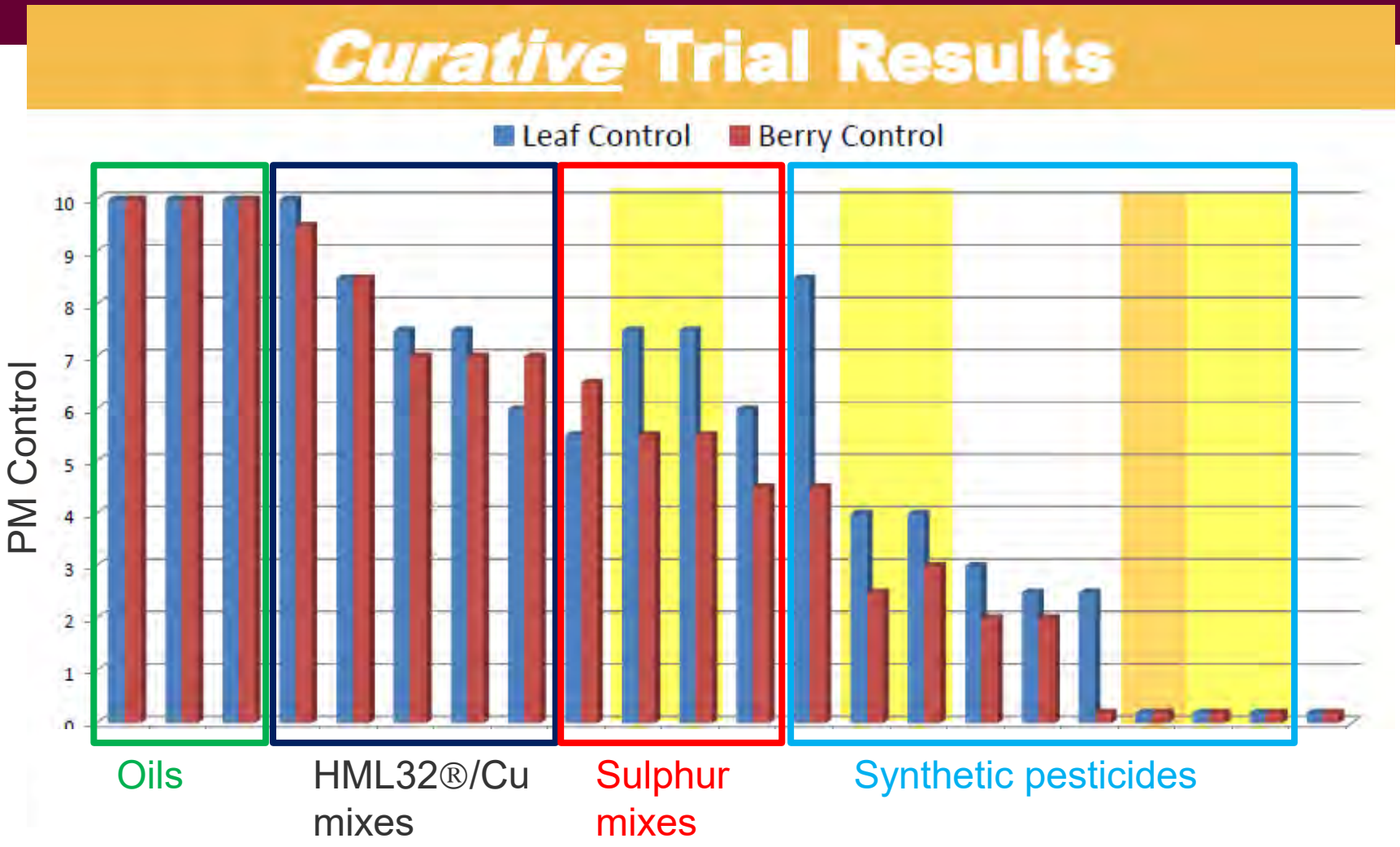
NP/Synthetic Fungicide Comparison

NPs	Synthetic Fungicides (SFs)
Resistance development risk = low	Increasing examples of resistance development
No residue	Residue problems if poorly timed
Safer to handle than SFs	Extensive personal protective equipment required
Minimal risk to the environment	Increased environmental risk
Suitable for conventional and organic markets	Conventional vineyards only
Efficacy equals or exceeds SFs when used according to label recommendations	Efficacy may be compromised by resistance
May not require wetters or spreaders	Wetters/spreaders usually required

Advantages of NPs over synthetic pesticides (2)



Trial results are from Chris Herries of Farmlands

Commercially Available NPs for Grape PM Control (in NZ)

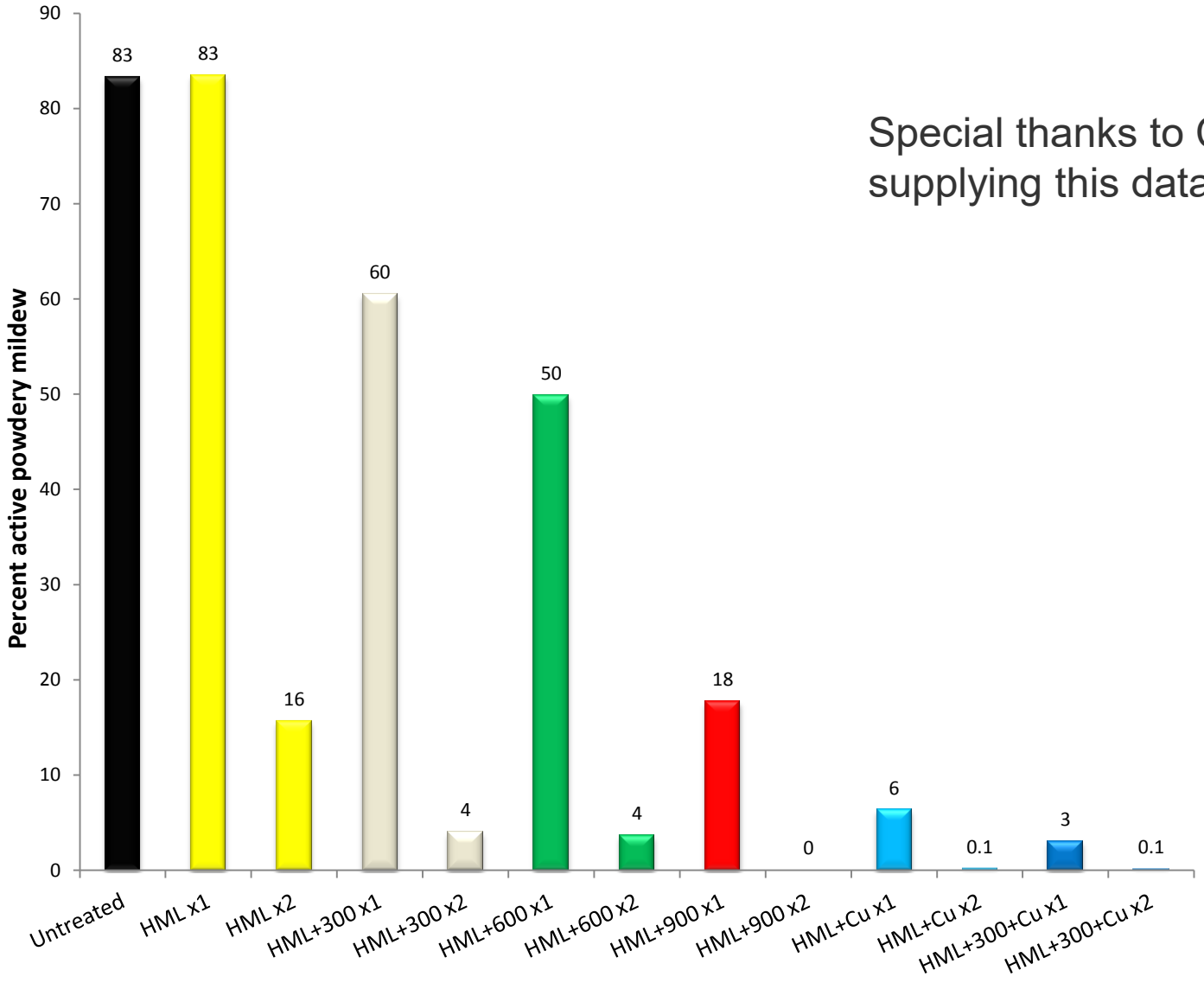
Product	Supplier	Active ingredient
MIDI-Zen®	BotryZen 2010 Ltd	Soybean oil (NP2)
HML32®	Henry Manufacturing Ltd	Fatty acids + potassium bicarbonate
Ecocarb®	Organic Crop Protectants	Potassium bicarbonate
Kumulus DF®	BASF	Sulphur
Serenade Max®*	Bayer Crop Science	*Bacillus subtillus*

*BCA – claimed to provide disease suppression only.

Natural Product Development Process (1)

- Efficacy & Phytotoxicity
  - lab, glasshouse, field trials
- Formulation
  - must not clog spray equipment
  - practicality/ease of use e.g. liquids must be concentrated
  - ingredients with GRAS status
  - rate, frequency of application
  - additives
  - cost

Importance of Formulation on Efficacy (data from Henry Manufacturing Ltd)



Special thanks to Chris Henry for supplying this data

Natural Product Development Process (2)

Stability/storage life
- no phase separation
- storage at room temp
- 2 yr shelf life (estimate by 2 wk at 54ºC)

•Yield
- quality & quantity of grape bunches
- sensory testing (no adverse effect on wines)

• Residue testing

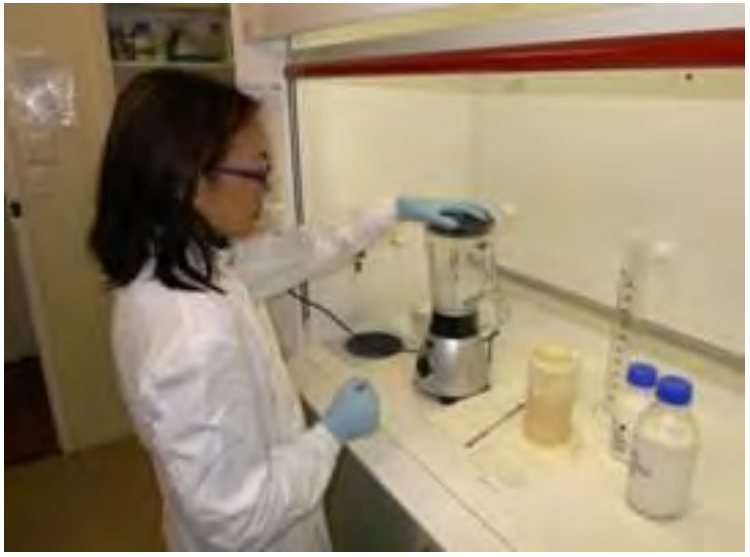
• IP Protection?

PFR NP Research on PM Control – NP1 & NP2

- Natural product 1 (NP1) = emulsified (oil in water emulsion) anhydrous milk fat (AMF)
- Natural product 2 (NP2) = emulsified soybean oil.

Sold commercially in NZ as MIDI-Zen®

- Typically formulated as concentrates of the fat/oil with additional GRAS status ingredients to maintain a stable emulsion and prolong shelf life



Extent of PFR Research on NP1 & NP2

Crop	Site	# Seasons (Pathogen)	Efficacy cf. synthetic fungicide	Phytotox.
Squash	Glasshouse	5 (PM)	As good as or better	Mild
Squash	Field	3 (PM)	Worse	Moderate
Zucchini	Glasshouse	1 (PM)	As good as	Mild
Wheat	Glasshouse	2 (PM)	As good as or better	None
Wheat	Field	1 (PM)	Confounded by rust	N/A
Roses (3 cv.s)	Glasshouse	3 (PM)	Better	None
Apples (2 cv.)	Glasshouse	2 (PM)	Better	None
Tomatoes	Glasshouse	2 (PM)	As good as or better	None
Grapes	Lab	Multiple (Bc)	As good as or better	None
Grapes	Glasshouse	2 (Bc)	As good as or better	None
Grapes	Field (5 diff areas)	7 (Bc) 3 (PM)	As good as or better	Mild (season 1)

Efficacy Data :NP1 & NP2 Control of PM on Squash

← NP1 vs.H_20 control

NP2 vs. H_20 control →

Efficacy Data: NP1 & NP2 Control of PM on Roses

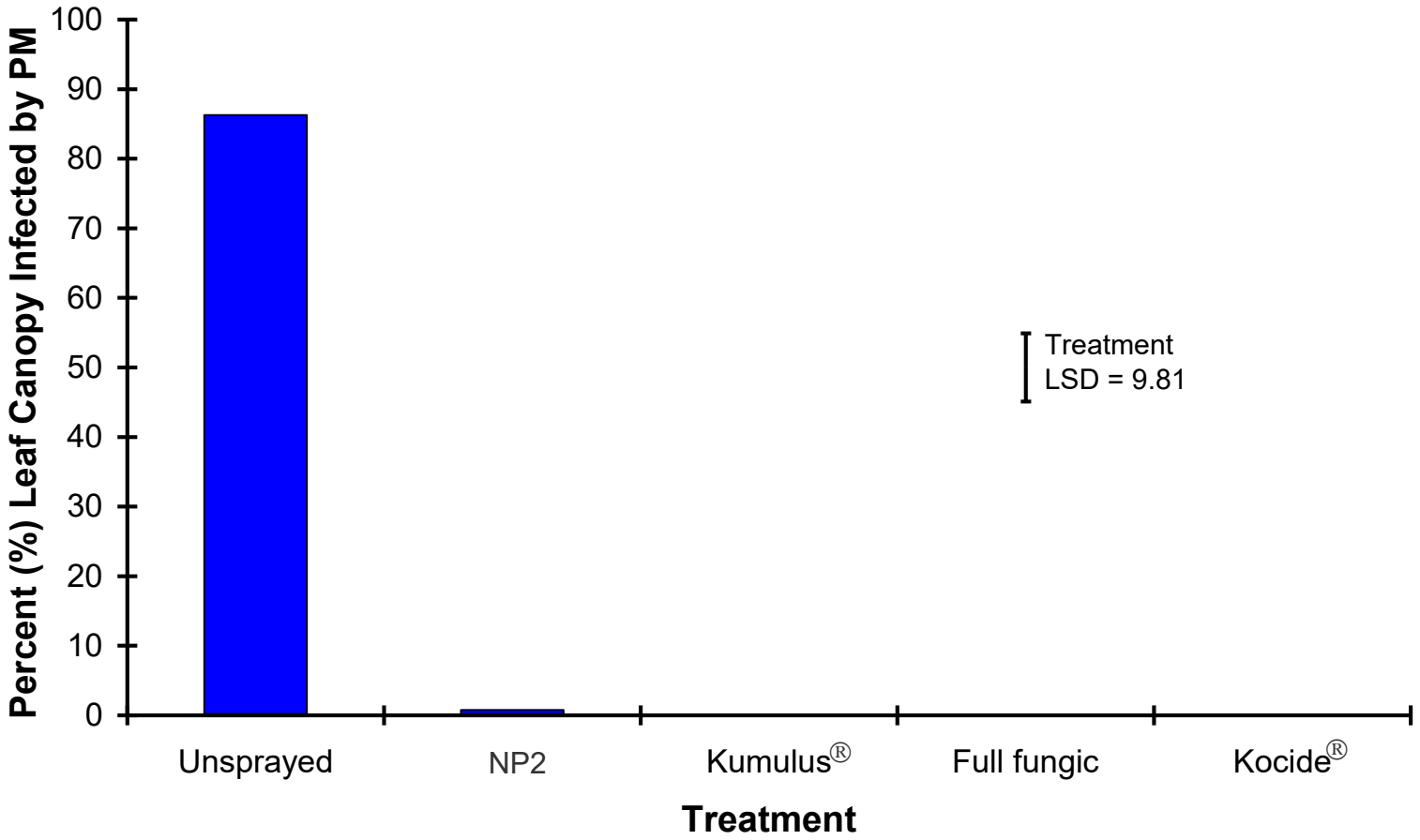
Unsprayed

NP1

NP2

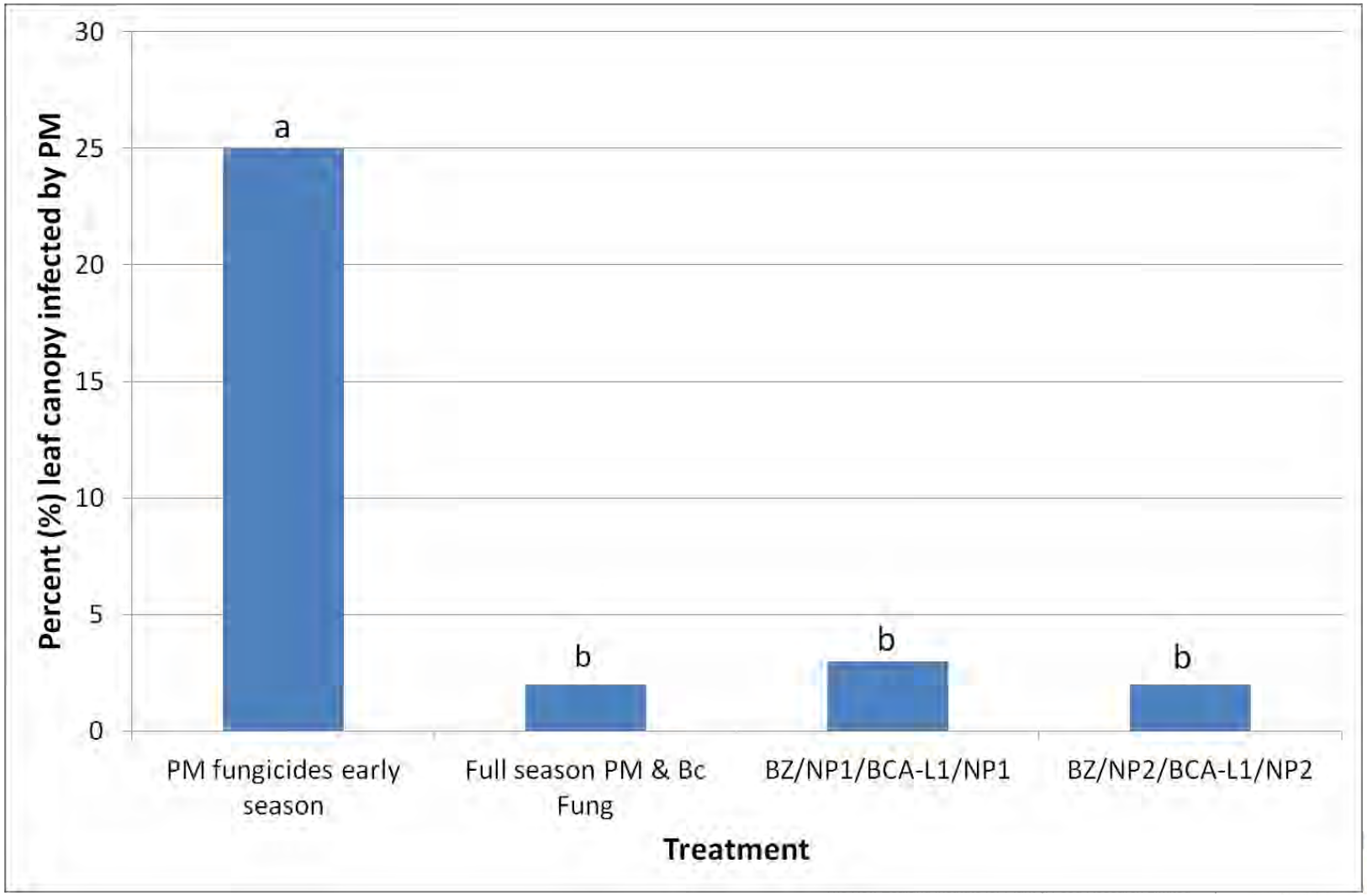
Efficacy Data: NP2 Control of PM on Grapes (1)

Season-long NP treatment – PM control on Chardonnay canopy



Efficacy Data: NP1 & NP2 Control of PM on Grapes (2)

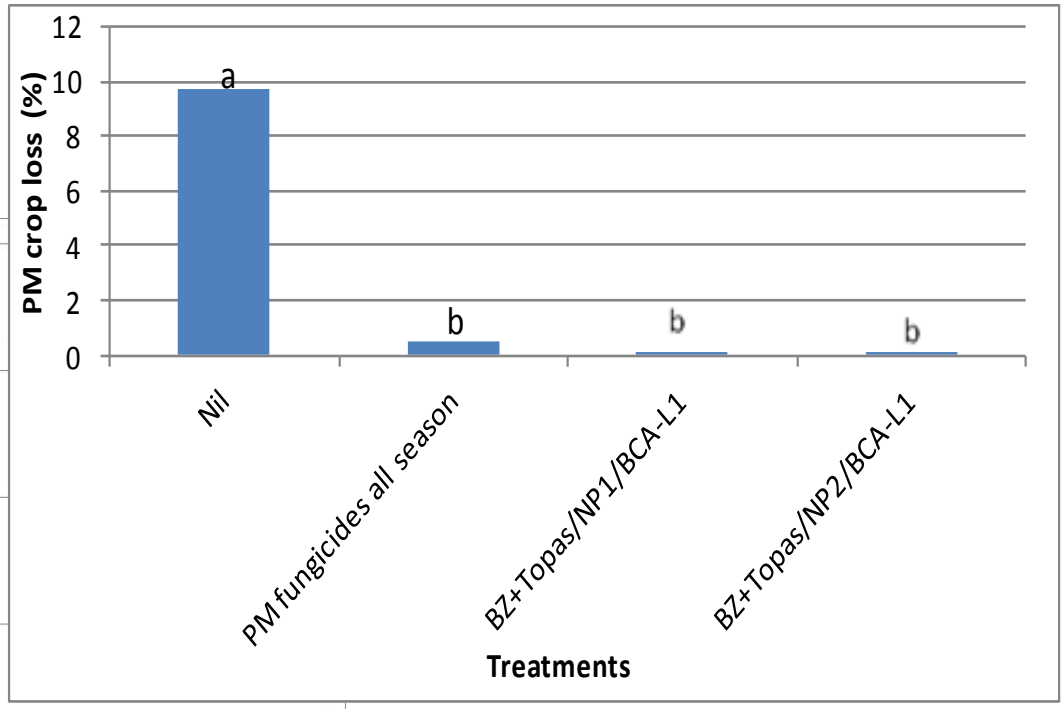
Mid/late season NP trt – PM control on Riesling canopy



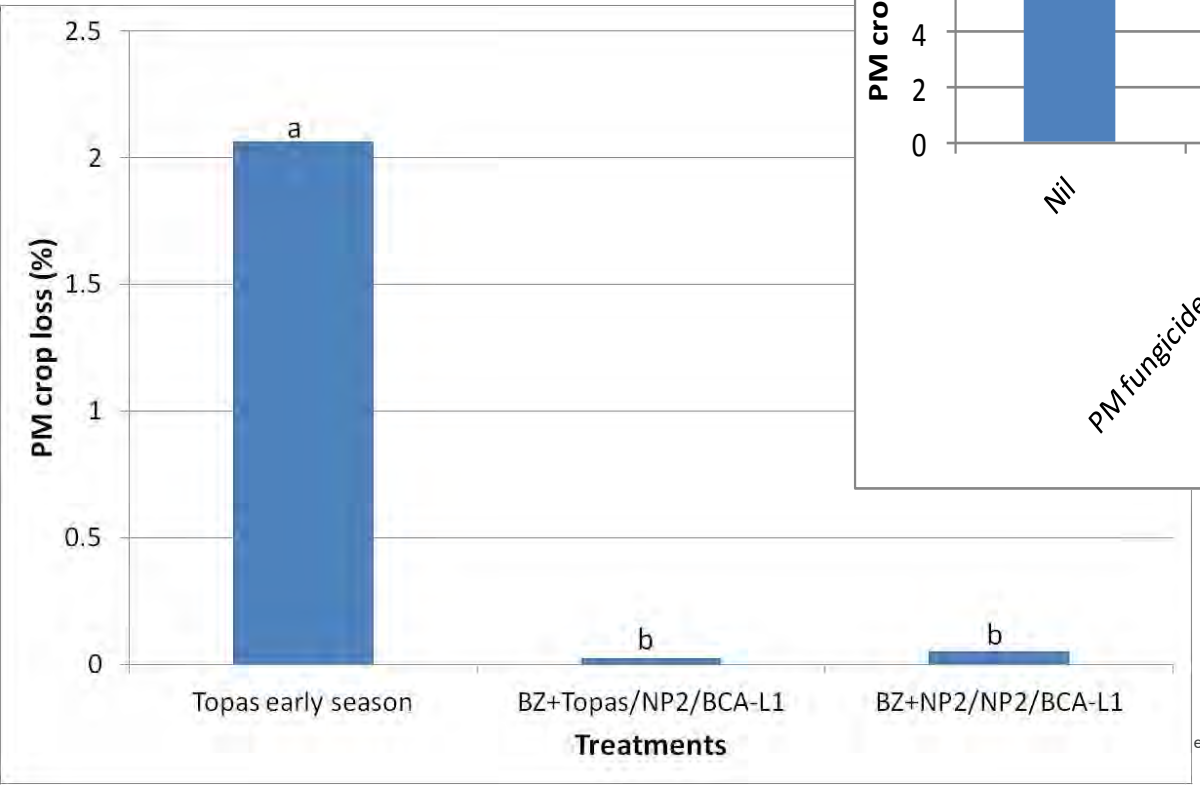
Efficacy Data: NP1 & NP2 Control of PM on Grapes (3)

Mid season NP trt – Control of PM on berries in: A) Chardonnay, & B) Sauvignon blanc

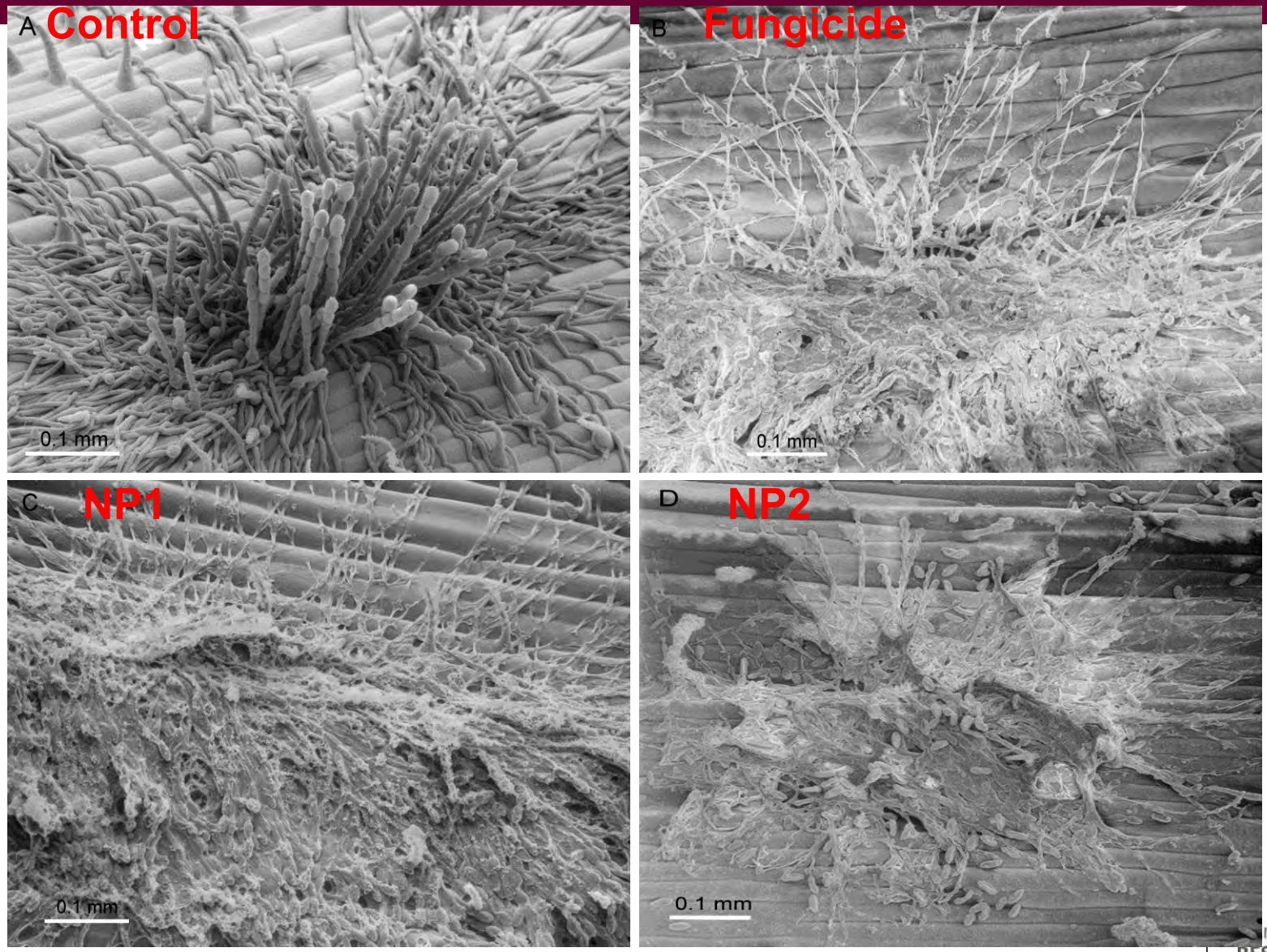
B)



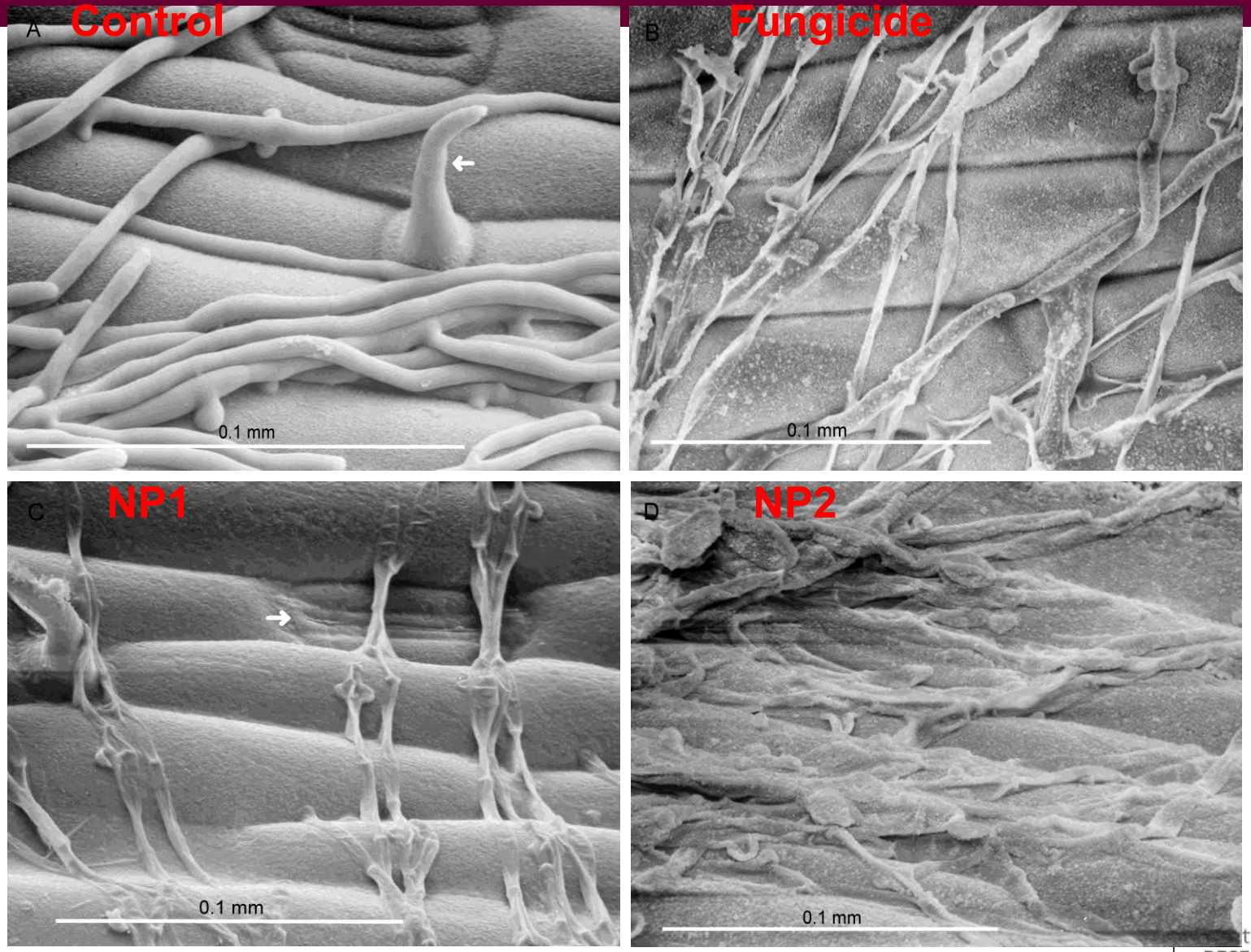
A)



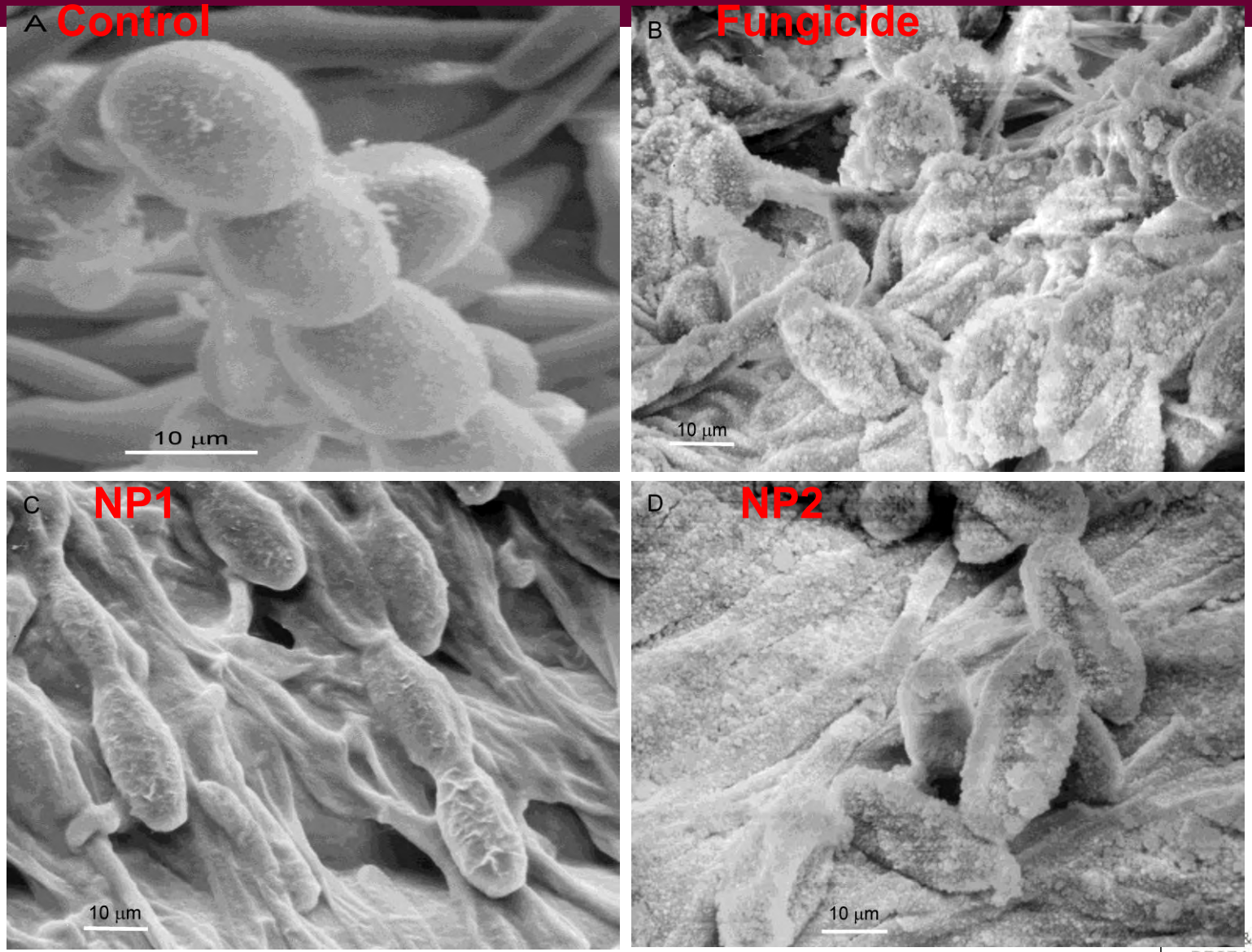
NP1 & NP2 Mode of Action (SEM photos of PM on wheat)



NP1 & NP2 Mode of Action (SEM of PM Hyphae on Wheat)



NP1 & NP2 Mode of Action (SEM of PM Conidiophores on Wheat)

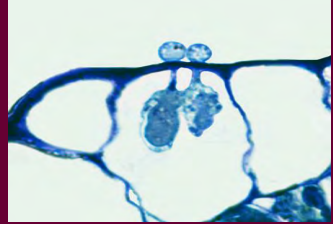


NP Best Practice

DO:

- Apply the product directly to the surfaces where disease control is required – direct spray access to the pathogen is pivotal (e.g. 70% bunch exposure in grapes preferred)
- Use these products primarily as protectants
- Calibrate your sprayer to achieve **thorough coverage** (bunch zone = canopy) & preferably maintain tank agitation while spraying

NP Best Practice



DO:

- Restrict applications to the recommended doses and frequencies
- Use these products as part of an IPM strategy.
- Be aware that using oils after véraison can delay brix in grapes (by no more than 1 wk)

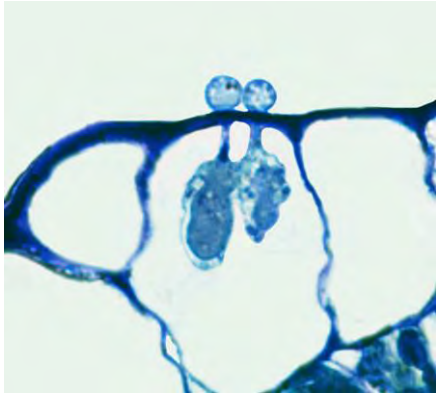
NP Best Practice

DON'T:

- Exceed application rate or frequency of application.
- Tank mix these products with other products unless specified as compatible on the label
- Apply the product if not properly emulsified (for oils)

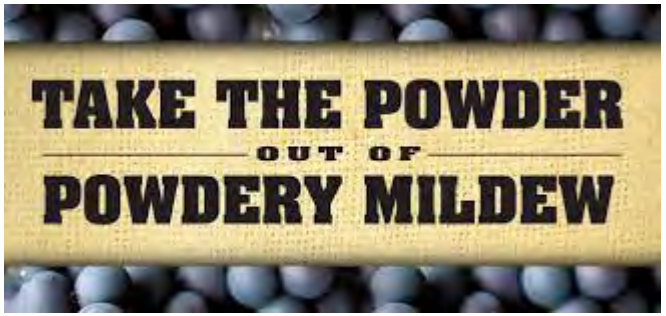
Conclusions

- NPs, **when used according to product guidelines**, can provide excellent PM control
- Given that many NPs are contact-only fungicides, their best use may within IPM programmes, to alternate with and thereby reduce use of SFs
- Cost of some NPs is high relative to SFs, but they offer many advantages over SFs
- There are no examples of resistance dvpt to fats/oils despite their use over decades e.g. JMS stylet oil®



Recommendations

- More extension/industry support to ensure uptake of NPs by grape sector
- Test NPs against DMI-resistant isolates.
- Develop more IPM-based programmes for grape sector.
- Gather more grape PM control data for NP1 & MIDI-Zen®



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Kirstin.Wurms@plantandfood.co.nz

Appendix 6. David Manktelow

NEW ZEALAND WINE
PURE DISCOVERY

SPRAY DEPOSITION AND DOSE
FOR POWDERY MILDEW MANAGEMENT

David Manktelow

freshLearn

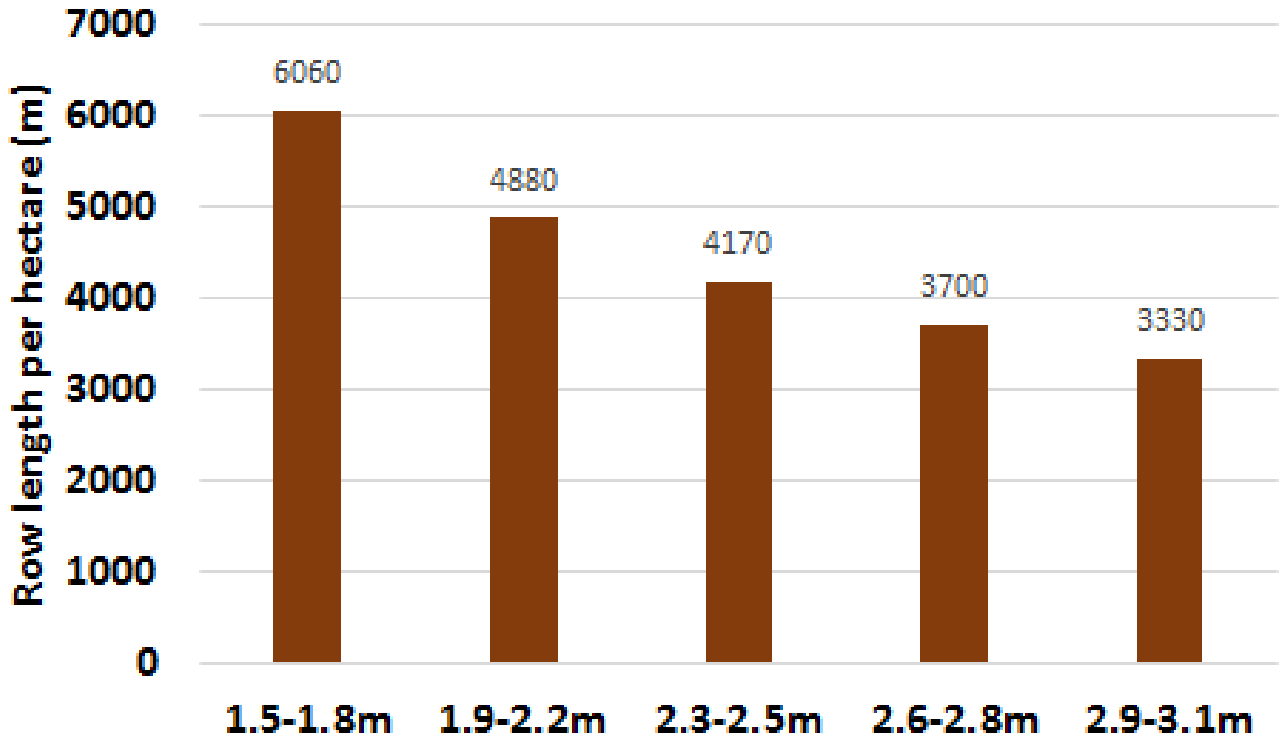
NEW ZEALAND WINE
PURE DISCOVERY

The biggest cause of poor outcomes when spraying any crop is a failure to deposit an effective chemical dose

What drives ineffective dosing?

- *Resistance development*
- *Bad spray timing*
- ***Applying too little chemical***
- ***Poor application/coverage***

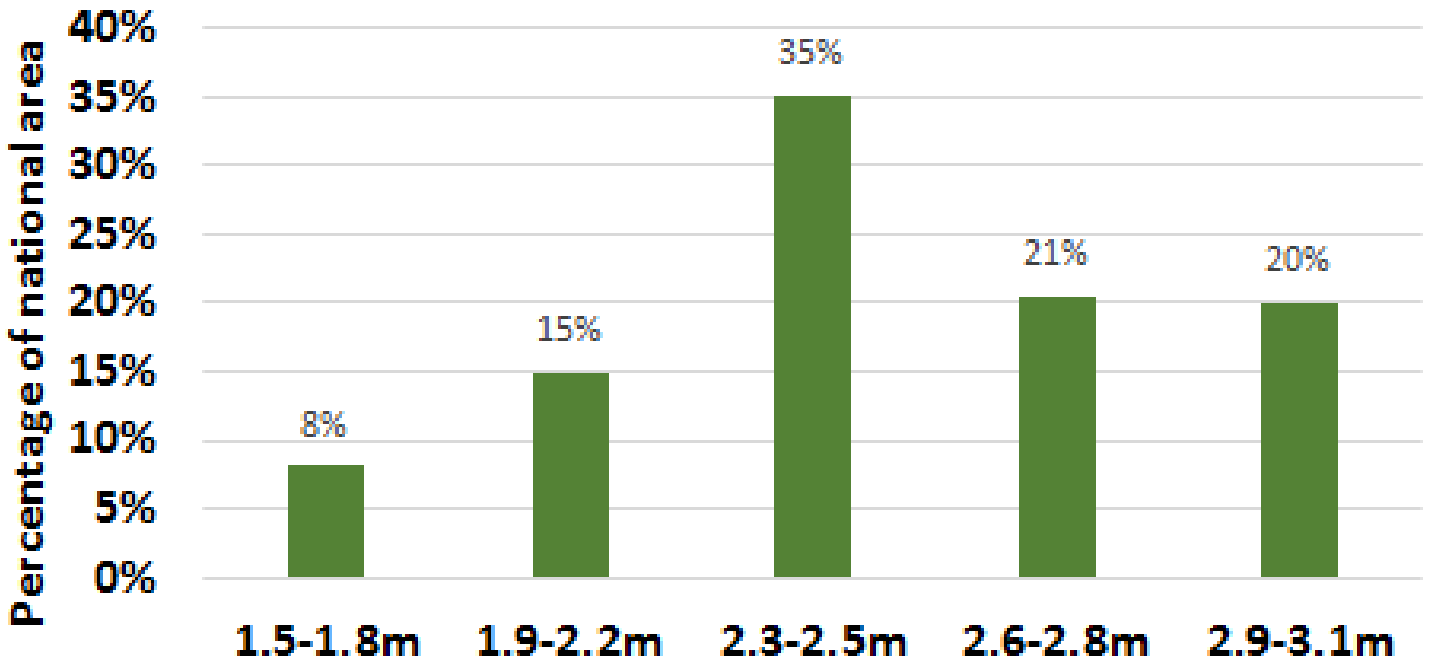
Row length per hectare for different row spacings



As planting systems intensify on narrower row spacings, the length of row to treat per hectare increases

NZ winegrape row spacings

2013 industry data area = 35,000 ha, 5633 blocks



58% of plantings are now on rows less than 2.5m wide

What does this imply for chemical application rates?

VSP in the spring around flowering

~ 1 m tall

~ 2 leaf layers thick

Gaps result in a spray retention efficiency of ~ 40-60%

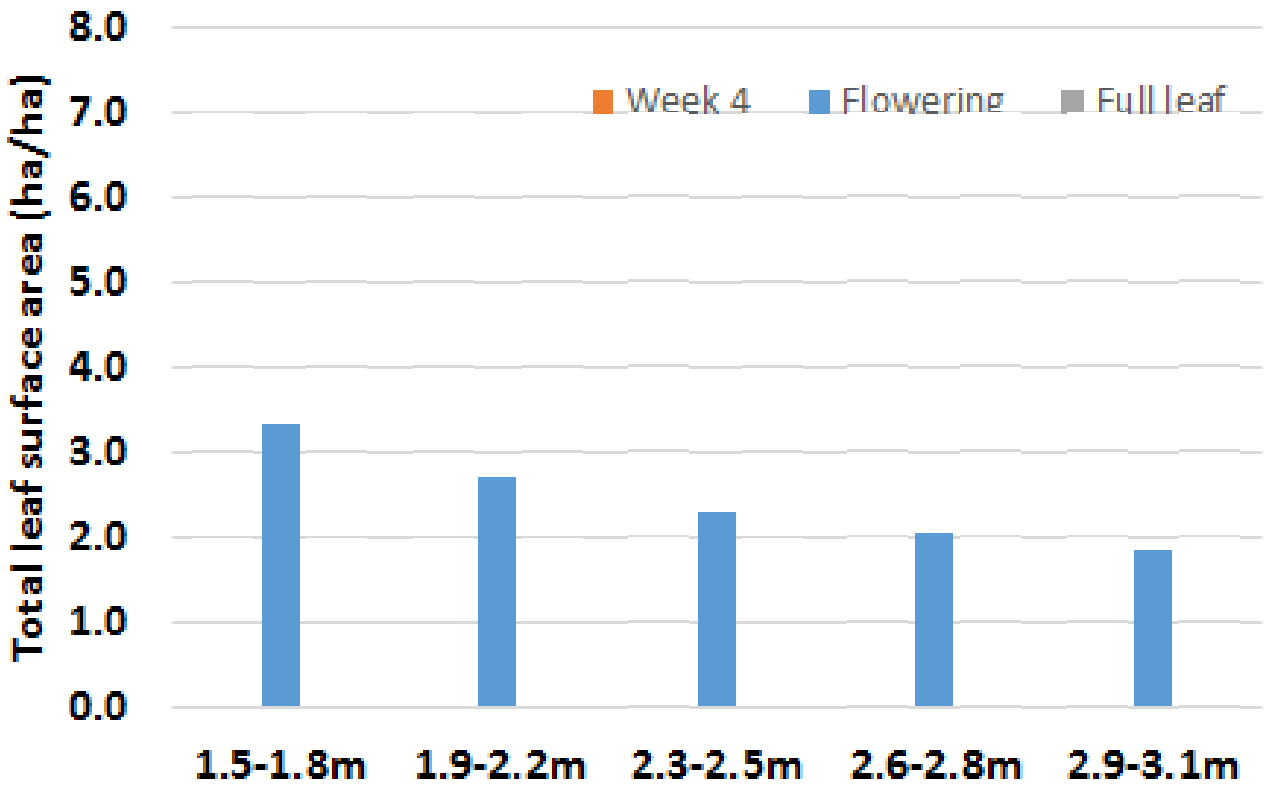
Target surface area (both sides of leaves) Will be approximately **4m^2/m of row**

Looking at a spring canopy around flowering

(and assuming that the same canopy is grown on all row spacings)

Estimated canopy surface area per hectare

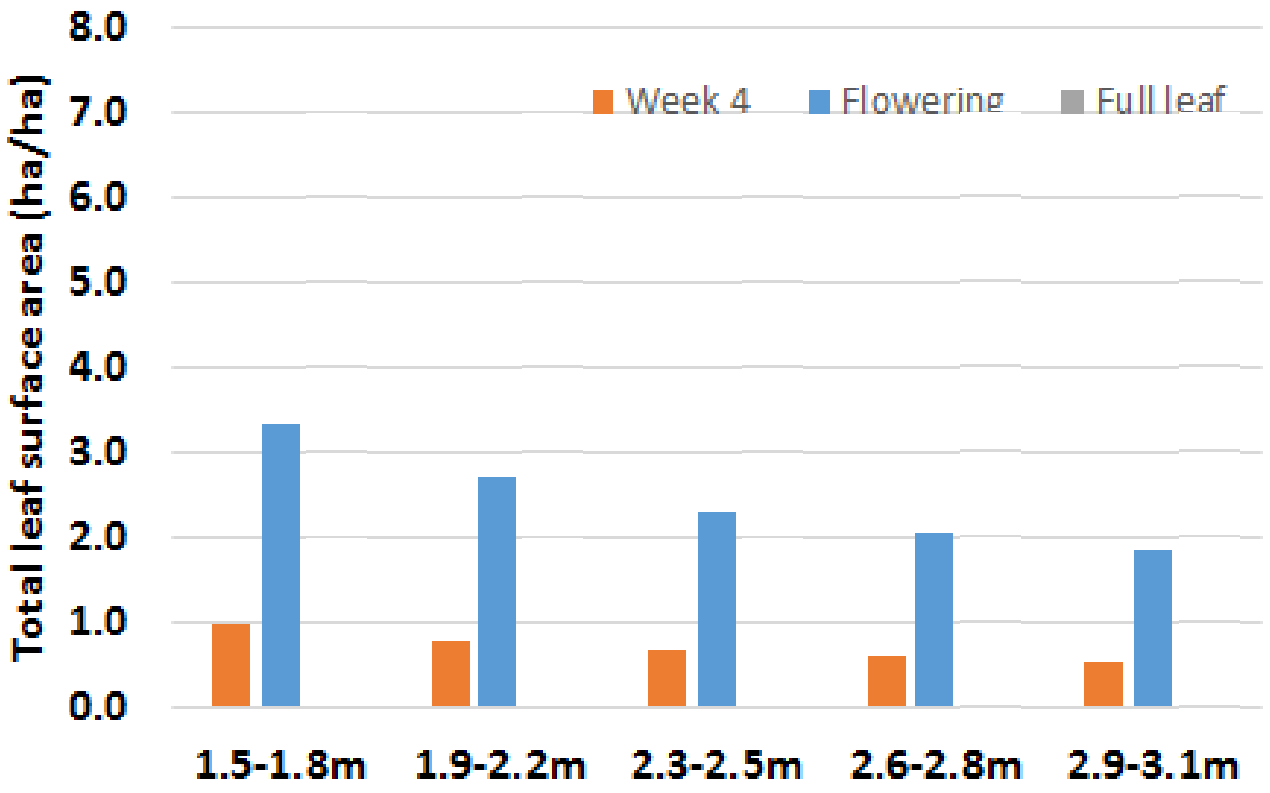
With stage of growth and row spacing (both leaf sides)



There is a bigger canopy surface area to spray on narrower row spacings…..

Estimated canopy surface area per hectare

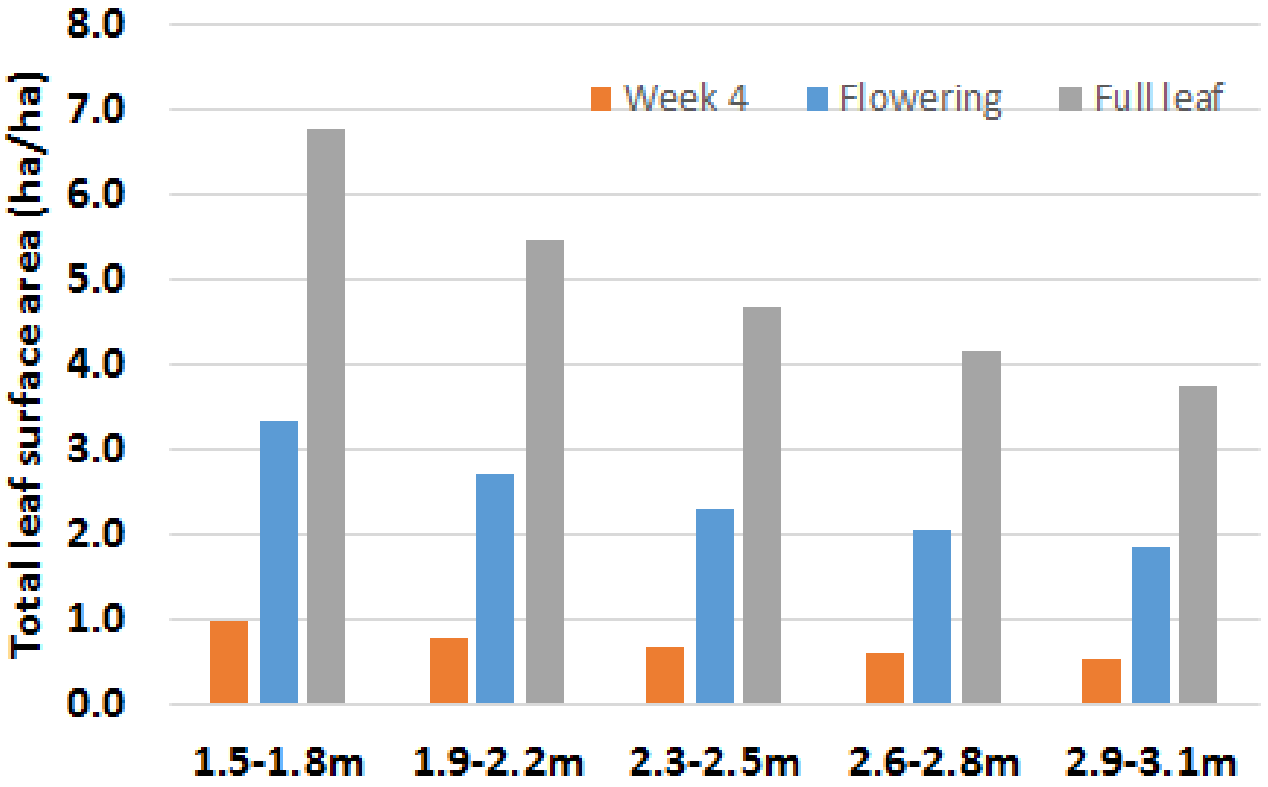
With stage of growth and row spacing (both leaf sides)



There is a lot less canopy to spray prior to flowering…..

Estimated canopy surface area per hectare

With stage of growth and row spacing (both leaf sides)



….and a lot more canopy develops after flowering.

- Canopies on closer row spacings have more surface area to treat than those on wider row spacings.
- As canopies grow through the season the surface area to cover with spray increases.
- So some sort of application rate adjustment is logically required

Spring adjustment is easy, just turn on more nozzles and apply more spray as shoots extend

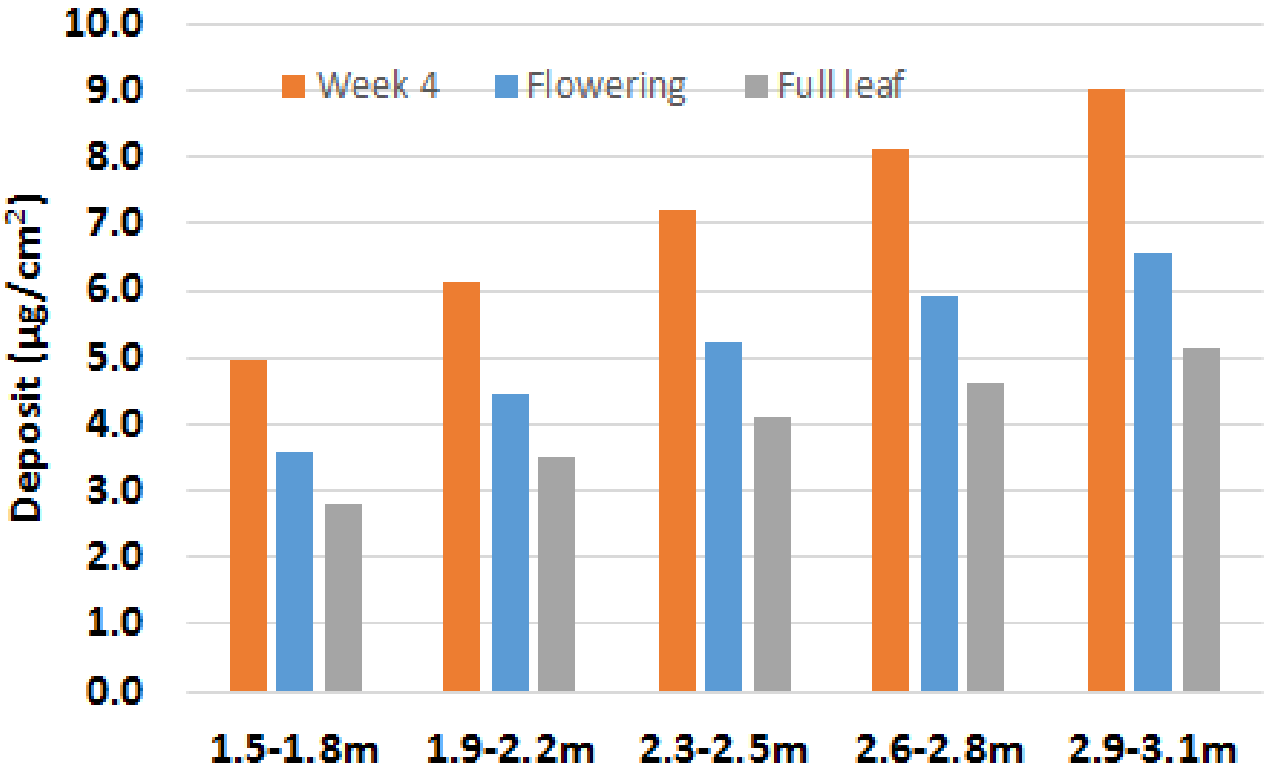
But…… chemical deposits per cm^2 are also a function of product application rate, spray retention efficiency on the target and deposit evenness on the target surface.

Spray retention efficiency increases as a canopy develops and fills out through the season.

Dormant bare canes = around 5%
By week four from bud break = around 20%
At flowering = around 50%
At bunch closure retention peaks = around 80%

Estimated average sulphur ai deposits

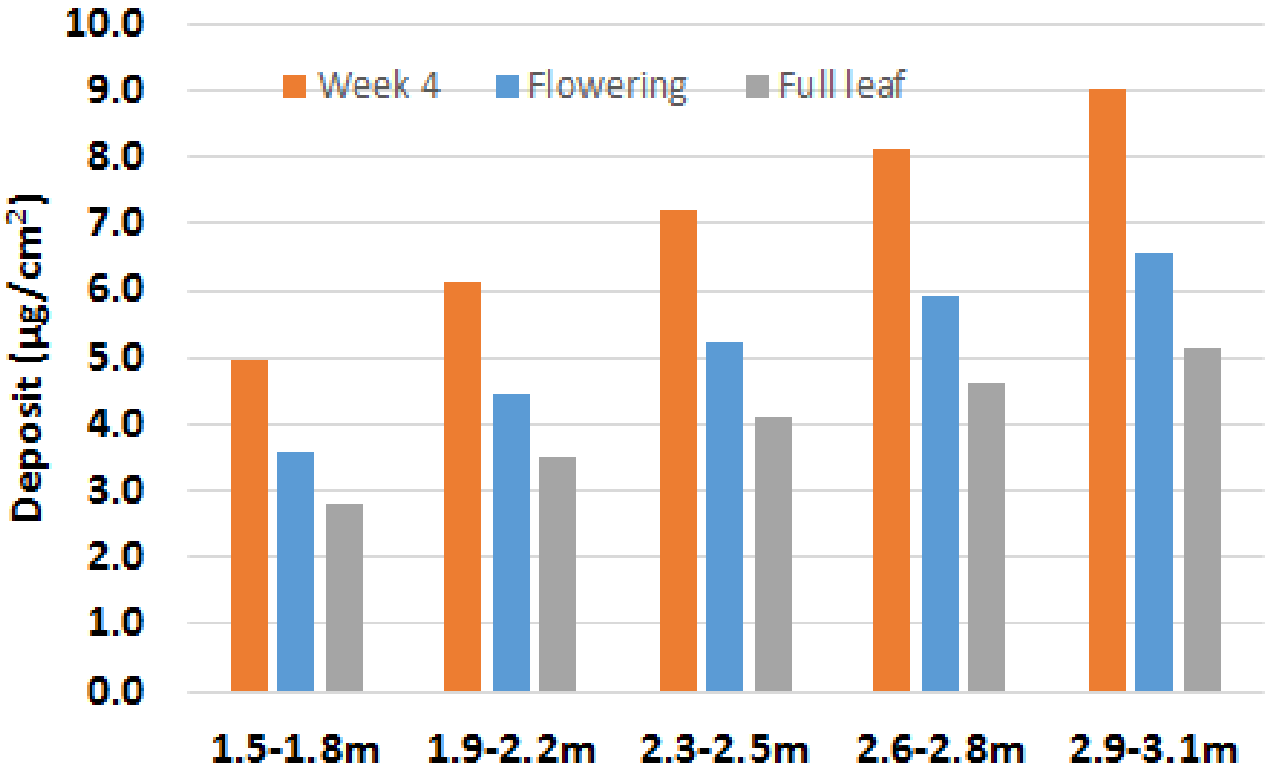
From Kumulus applied at 3kg/ha



Increasing spray retention efficiency helps maintain dose as the canopy grows through the season (20%-50%-80%)

Estimated average sulphur ai deposits

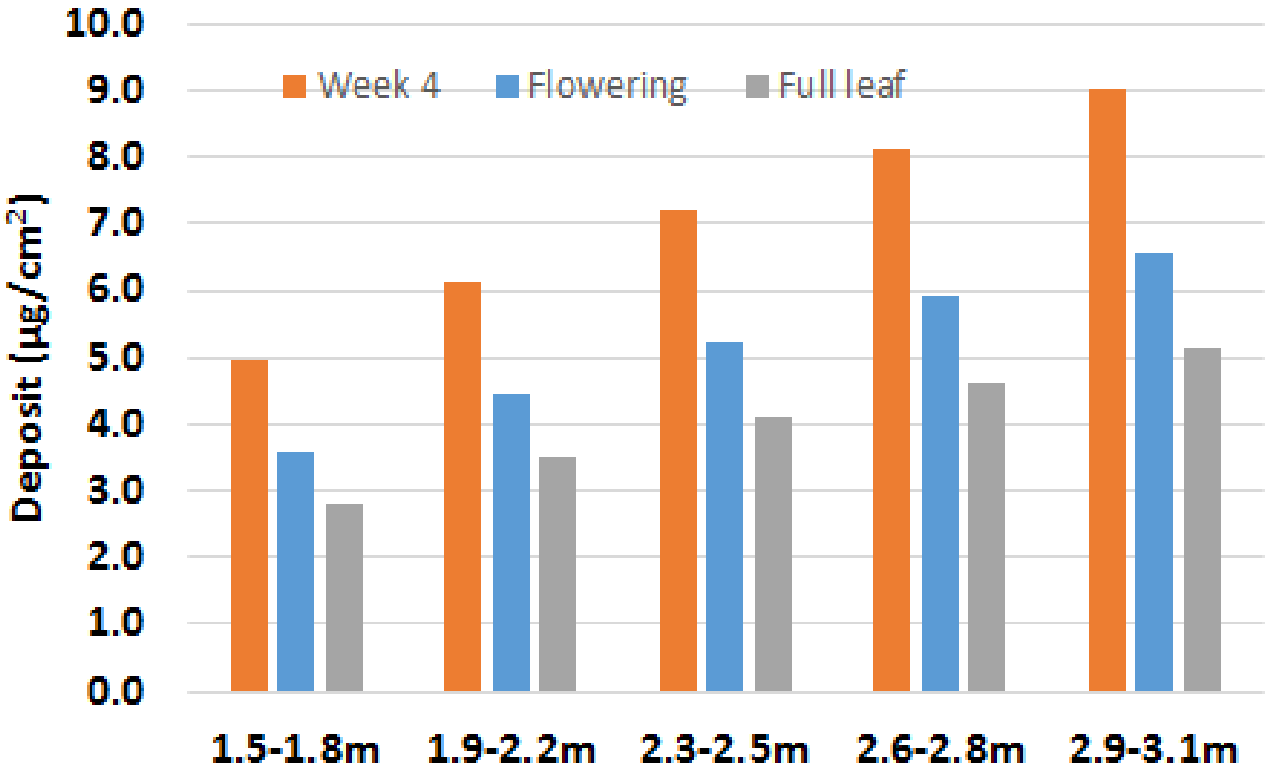
From Kumulus applied at 3kg/ha



If the same rate per hectare was used for the whole season average spring deposits will be about 30% more than at full leaf

Estimated average sulphur ai deposits

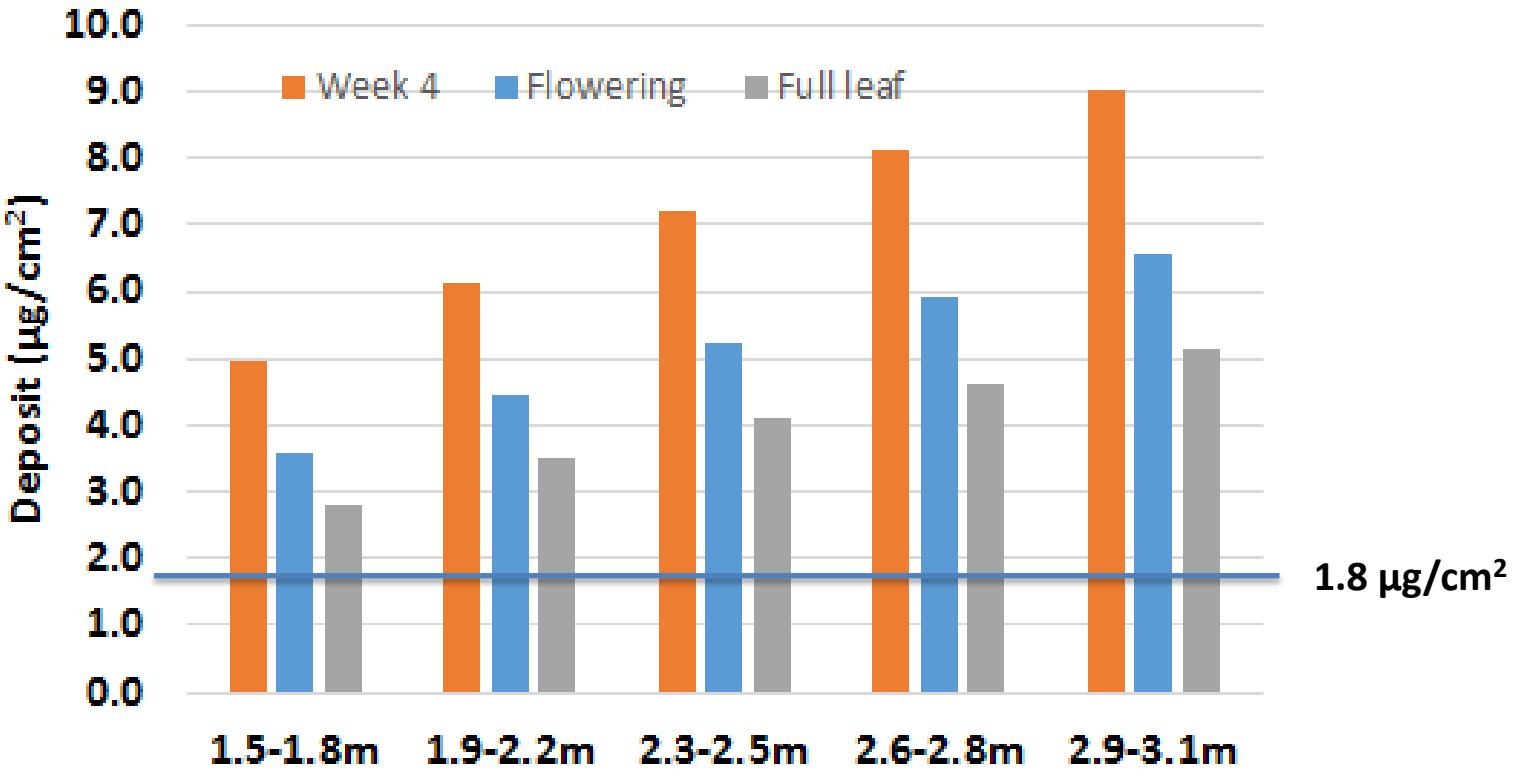
From Kumulus applied at 3kg/ha



The potential difference in deposits caused by row spacing is more important than the difference caused by growth!

Estimated average sulphur ai deposits

From Kumulus applied at 3kg/ha



But these are average deposits. How does dose vary through grape canopies?

NEW ZEALAND WINE
PURE DISCOVERY

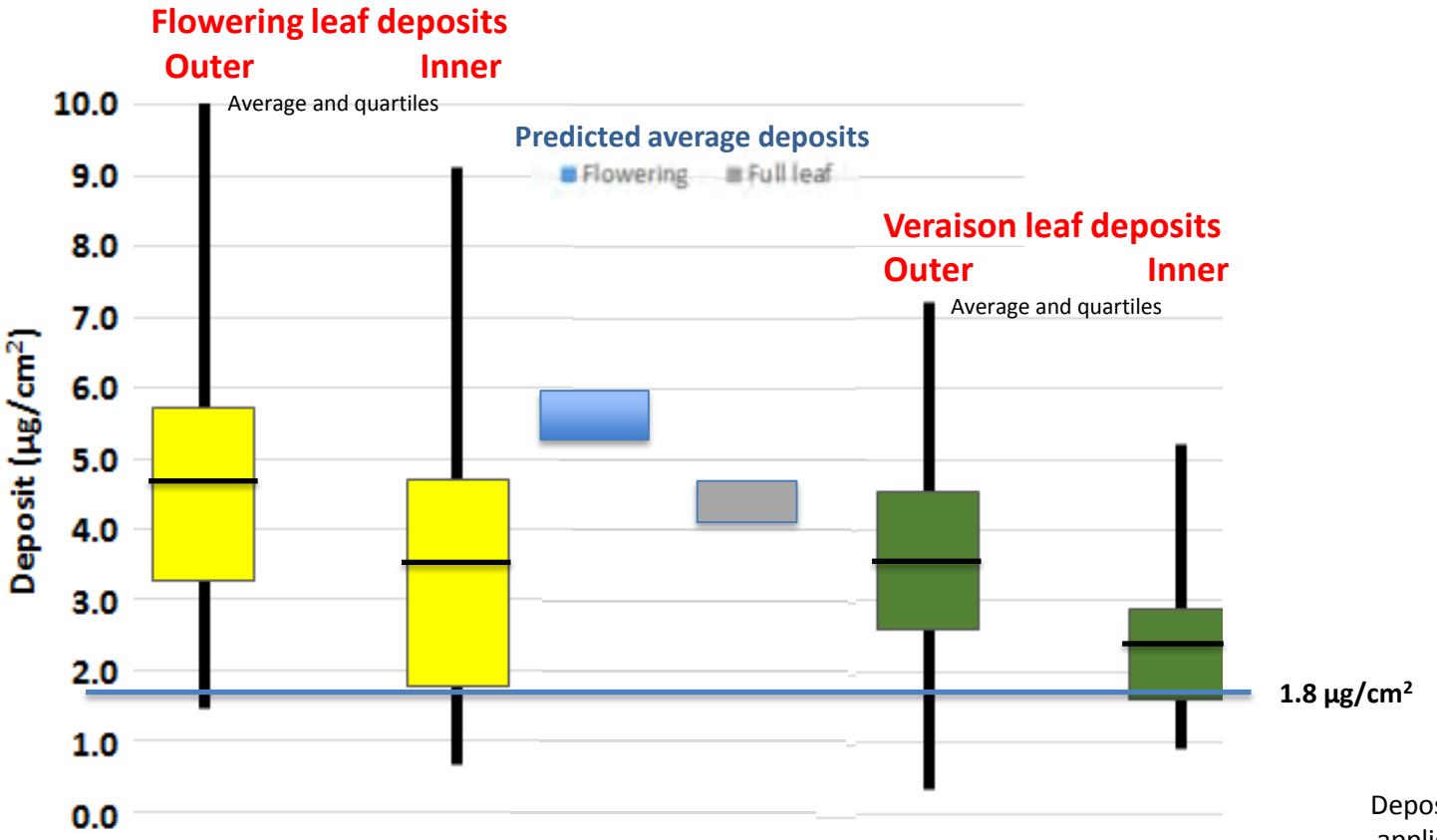
Dose variation rules of thumb

1) **Inner canopy zones will get about half the deposit seen on the outer canopy**

2) **Deposits on the least sprayed side of expanded leaves (usually the lower surface) will be half to a third of those on the most sprayed side.**

3) **Deposits per square centimetre of bunch surface area will be about half those on leaves.**

Expect a three-fold variation from exposed outer leaves to the least sprayed side of inner canopy leaves

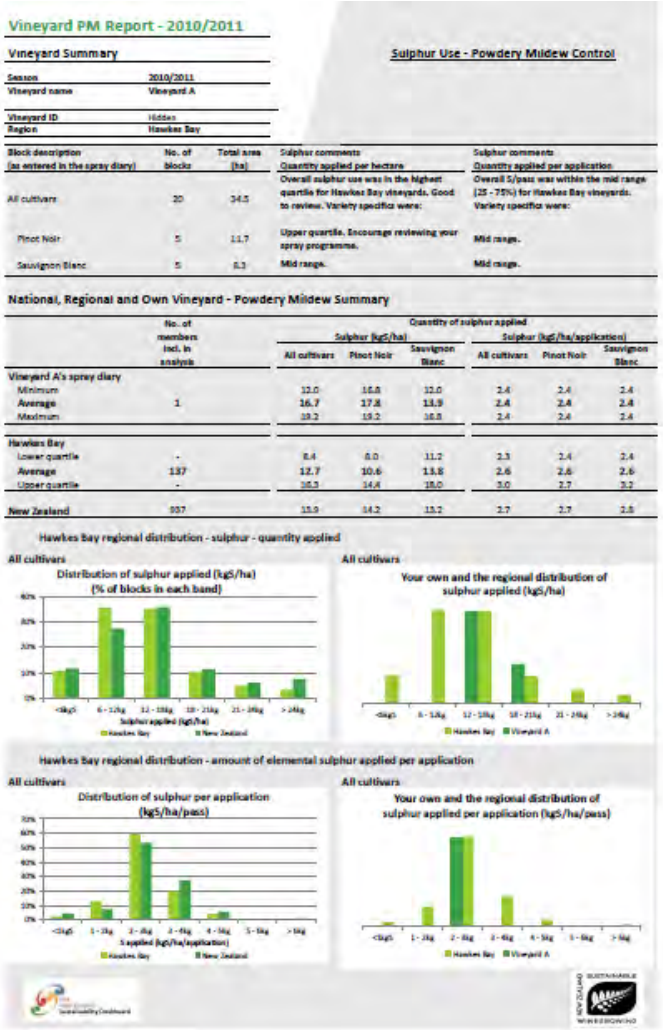


Deposits for application of 2.4 kg ai/ha

Powdery mildew control requires; the right products, sensible rates, a good spray programme and effective application.

NEW ZEALAND WINE
PURE DISCOVERY

Benchmarking industry spray programmes



Vineyard PM Report - 2010/2011

Vineyard Summary

Season	2010/2011
Vineyard name	Vineyard A
Vineyard ID	Hidden
Region	Hawkes Bay

Sulphur Use - Powdery Mildew Control

Block description (as entered in the spray diary)	No. of blocks	Total area (ha)	Sulphur comments Quantity applied per hectare	Sulphur comments Quantity applied per application
All cultivars	20	34.5	Overall sulphur use was in the highest quartile for Hawkes Bay vineyards. Good to review. Variety specific were:	Overall S/pass was within the mid range (25 - 75%) for Hawkes Bay vineyards. Variety specific were:
Pinot Noir	5	11.7	Upper quartile. Encourage reviewing your spray programme.	Mid range.
Sauvignon Blanc	5	8.3	Mid range.	Mid range.

National, Regional and Own Vineyard - Powdery Mildew Summary

	No. of members incl. in analysis	Quantity of sulphur applied: Sulphur (kgS/ha) All cultivars	Sulphur (kgS/ha) Pinot Noir	Sulphur (kgS/ha) Sauvignon Blanc	Sulphur (kgS/ha/application) All cultivars	Sulphur (kgS/ha/application) Pinot Noir	Sulphur (kgS/ha/application) Sauvignon Blanc
Vineyard A's spray diary							
Minimum		12.0	16.8	12.0	2.4	2.4	2.4
Average	1	16.7	17.8	13.9	2.4	2.4	2.4
Maximum		19.2	19.2	16.8	2.4	2.4	2.4
Hawkes Bay							
Lower quartile	-	8.4	8.0	11.2	2.3	2.4	2.4
Average	137	12.7	10.6	13.8	2.6	2.6	2.6
Upper quartile	-	16.3	14.4	15.0	3.0	2.7	3.2
New Zealand	937	15.9	14.2	13.2	2.7	2.7	2.8

Hawkes Bay regional distribution - sulphur - quantity applied

All cultivars — Distribution of sulphur applied (kgS/ha) (% of blocks in each band)

All cultivars — Your own and the regional distribution of sulphur applied (kgS/ha)

Hawkes Bay regional distribution - amount of elemental sulphur applied per application

All cultivars — Distribution of sulphur per application (kgS/ha/pass)

All cultivars — Your own and the regional distribution of sulphur applied per application (kgS/ha/pass)

The new reporting functions from Sustainable Winegrowing NZ aim to help you compare your practices with the rest of the industry.

Examples from 2012-13

(560 vineyards 2600 blocks)

Benchmarking spray application volumes

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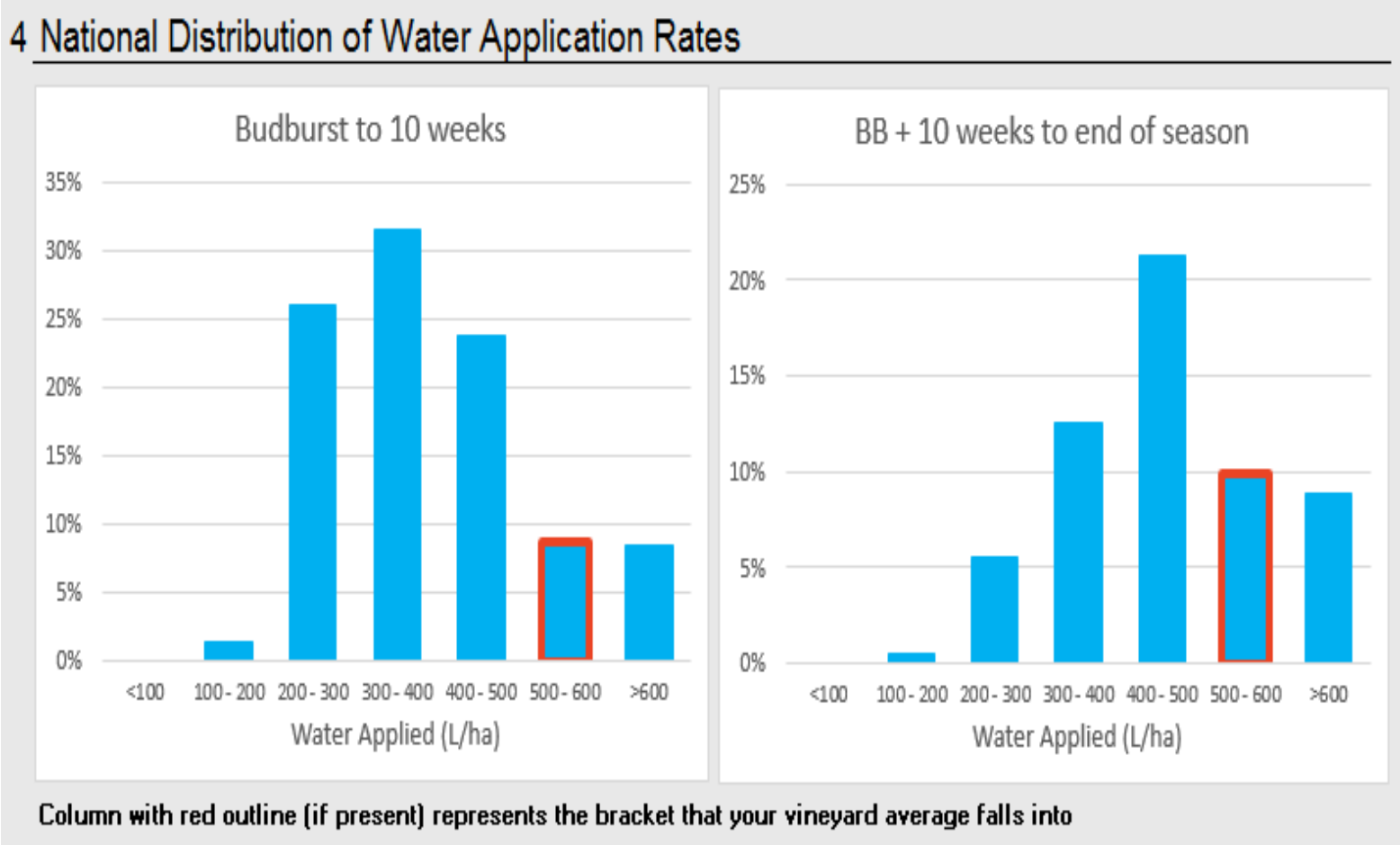
PURE DISCOVERY

- *Spray application volumes look OK*
- *Application volumes have increased*
- *But definitely a concentrate spraying industry*



Benchmarking application intervals:

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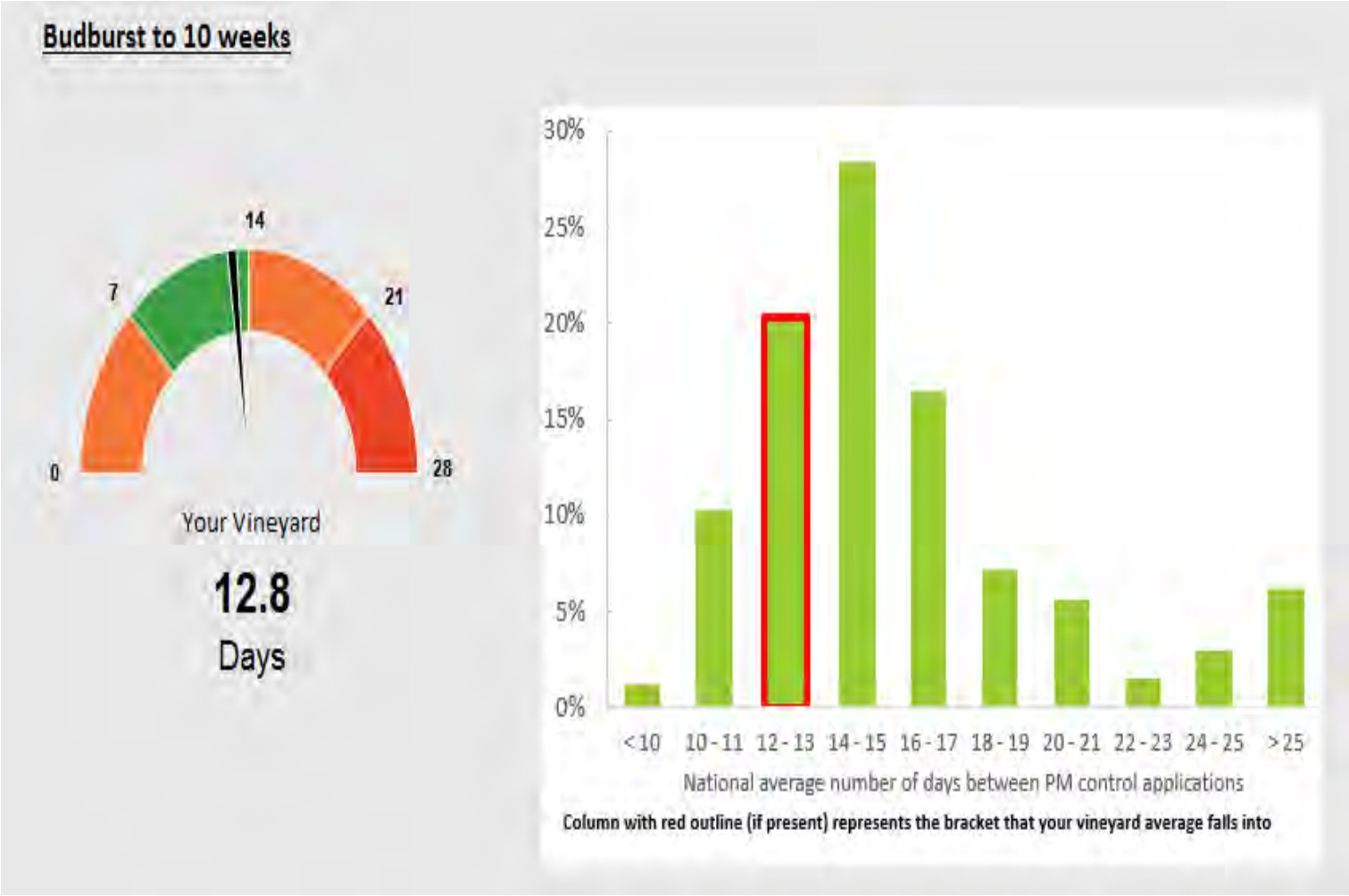
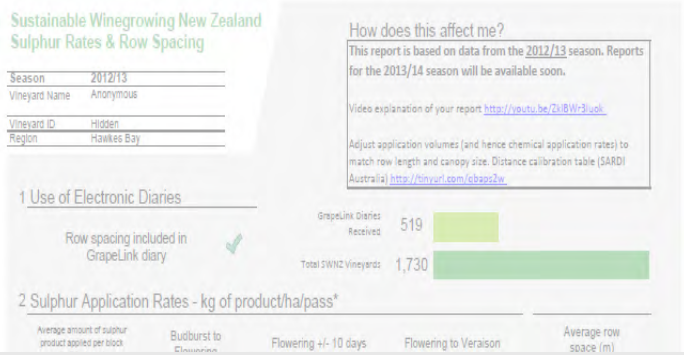
- *Powdery mildew spray application intervals are erratic*
- *> 30% of vineyards show excessive spray intervals?*



Benchmarking sulphur application rates


Sustainable Winegrowing New Zealand
Sulphur Rates & Row Spacing

Season 2012/13
Vineyard Name Anonymous
Vineyard ID Hidden
Region Hawkes Bay

How does this affect me?
This report is based on data from the 2012/13 season. Reports for the 2013/14 season will be available soon.
Video explanation of your report http://youtu.be/2kIBWr3luok
Adjust application volumes (and hence chemical application rates) to match row length and canopy size. Distance calibration table (SARDI Australia) http://tinyurl.com/qbaps2w

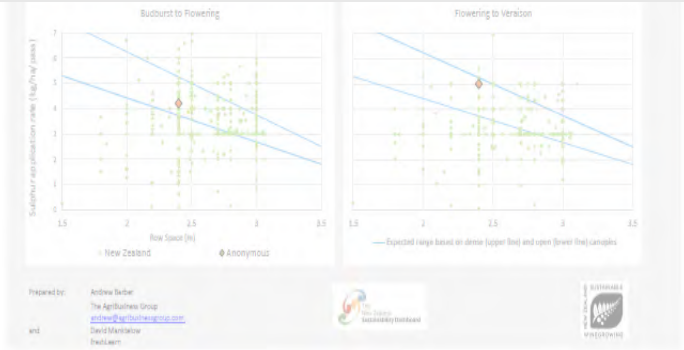
1 Use of Electronic Diaries
Row spacing included in GrapeLink diary
GrapeLink Diaries Received 519
Total SWNZ Vineyards 1,730

2 Sulphur Application Rates - kg of product/ha/pass*
Average amount of sulphur product applied per block | Budburst to Flowering | Flowering +/- 10 days | Flowering to Veraison | Average row space (m)

2 Sulphur Application Rates - kg of product/ha/pass*

Average amount of sulphur product applied per block (kg/ha/pass)	Budburst to Flowering	Flowering +/- 10 days	Flowering to Veraison	Average row space (m)
Your Vineyard	4.2	5.0	5.0	2.4
Hawkes Bay	3.1	3.2	3.1	2.6
New Zealand	3.5	3.5	3.3	2.6

*Most sulphur products have an active ingredient concentration of 80%, i.e. 1 kg of product = 0.8 kg of sulphur.



Drilling into sulphur application rate data

- *Vineyard intensification*
- *Meets counter Intuitive sulphur application rate decisions*
- *ca. 40% of blocks are being under-dosed*

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Dose variations measured at flowering on a Hawkes Bay vineyard

Grape Futures trial work in 2008-09

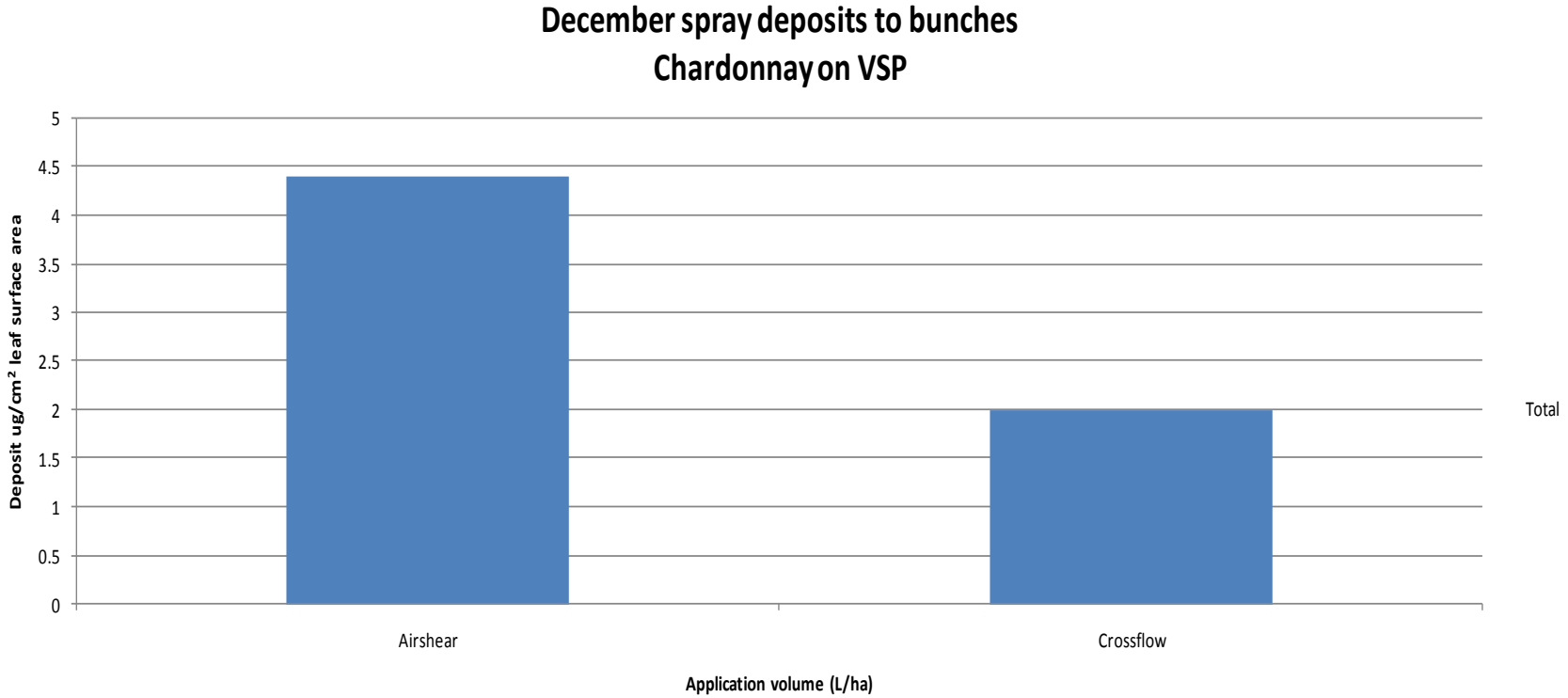
Coverage and deposit assessments

- *at flowering*
- *three application volumes*
- *two sprayers*
- *VSP chardonnay 2.8 m rows*

Flowering tests
Deposits versus coverage

VSP Chardonnay just post bloom
Two different sprayers
60% of output to bunch zone
40% to upper canopy

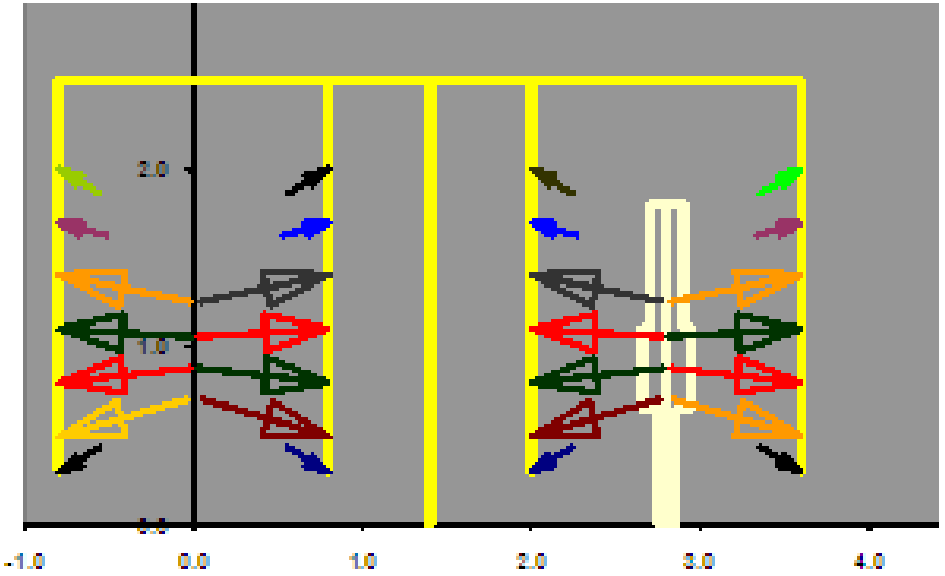
Leaf deposits by sprayer



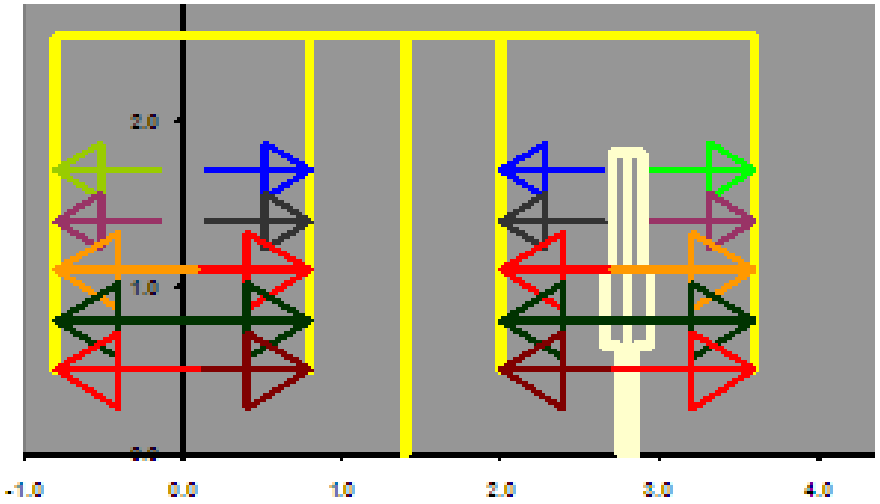
- Two-fold difference
- Due to poor sprayer targeting

Silvan Evo

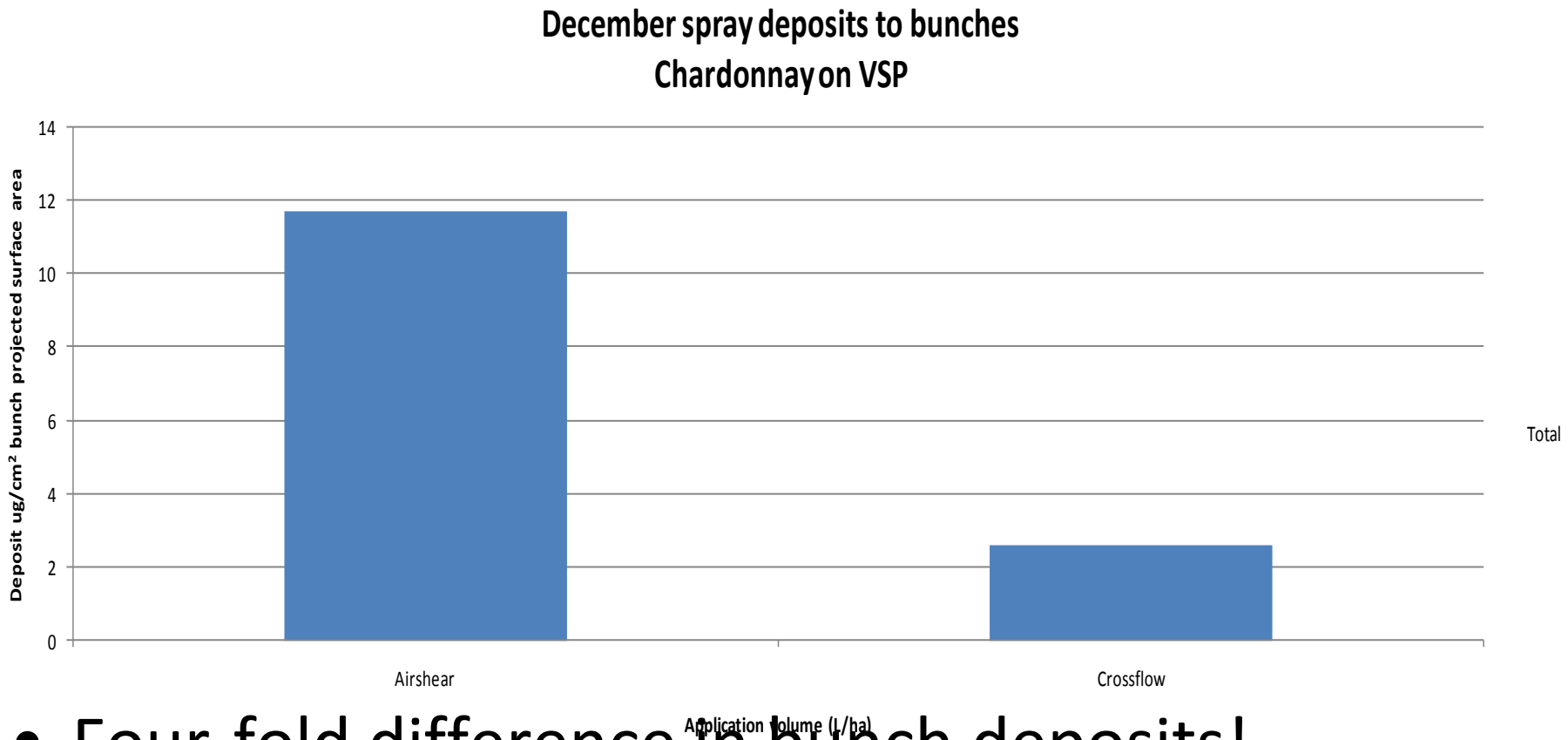
(Air shear)



Bertolini
(Tangential)



Bunch deposits by sprayer



- Four-fold difference in bunch deposits!
- Poor targeting
- Poor outcomes?

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But how would a grower know?

Experience a disease outbreak!

Steps to avoiding problems

1) **Optimise sprayer setup**
2) **Confirm spray coverage**
3) **Match chemical application rates to the target**
4) Manage spray programmes – intervals/product choices/resistance management

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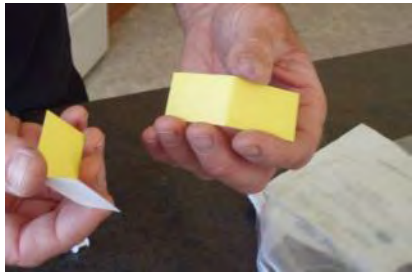
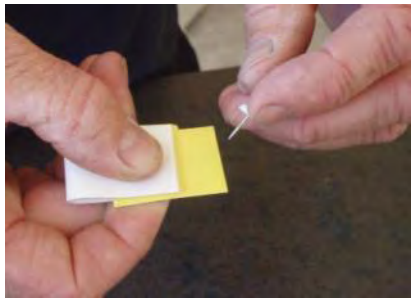
Sprayer setup to achieve good coverage

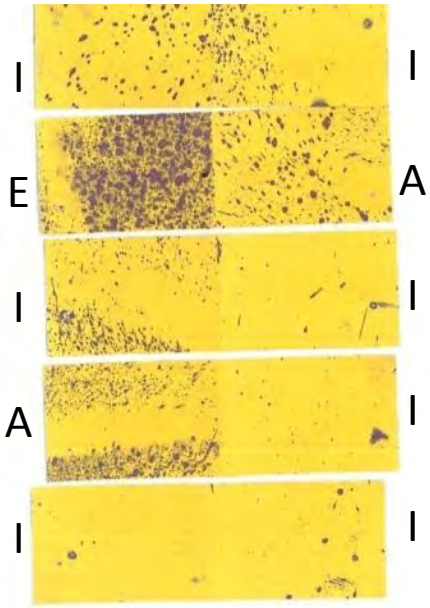
- ***Park the sprayer in a row***
  - ***Turn off nozzles that will miss the target***
  - ***Adjust nozzle angles to maximise penetration and coverage***
- ***Direct at least 60% of output to the bunch zone***
  - ***more is required on wider bunch zones (Sylvoz)***
- ***Give spray a chance to penetrate to the inner canopy***
  - ***Don't go too fast (6-8 km/hr is good)***
  - ***Maintain spray volumes (300-400 l/ha is good)***
- ***Monitor and improve spray coverage***
  - ***Identify and fix problems***
  - ***Learn to use adjuvant technology***
- ***Learn to look knowingly at operating sprayers***
  - ***Symmetry is good***
  - ***Look for penetration on upwind side***

Coverage testing using water sensitive papers

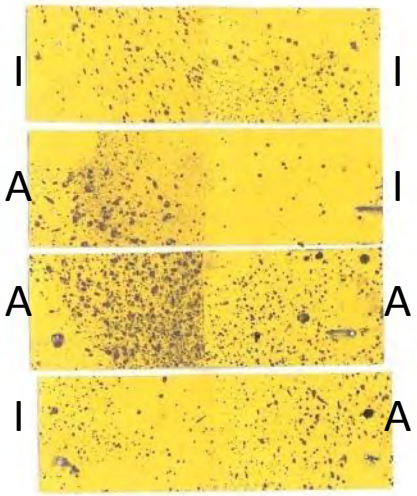




Inner bunches



Outer bunches

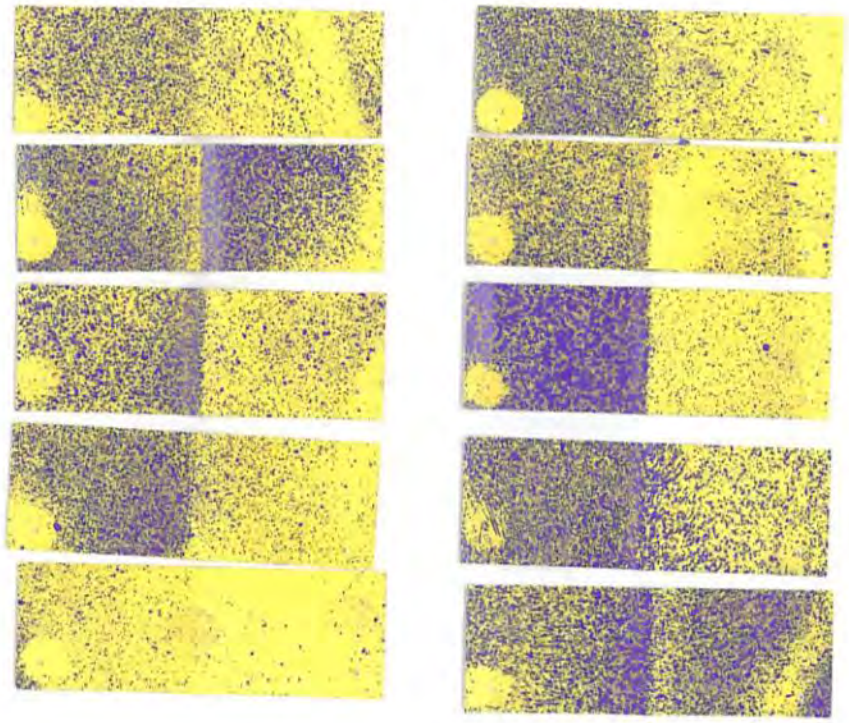


>60% Inadequate cover
Target >85% Adequate or Excellent

Even the good can get better……

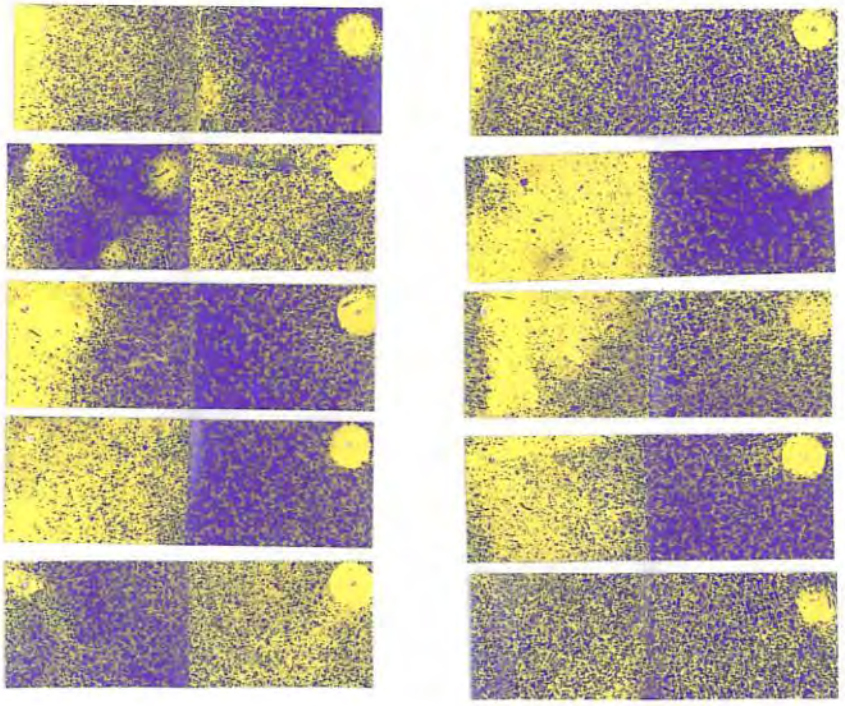
Inner bunches

Outer bunches



Inner bunches

Outer bunches



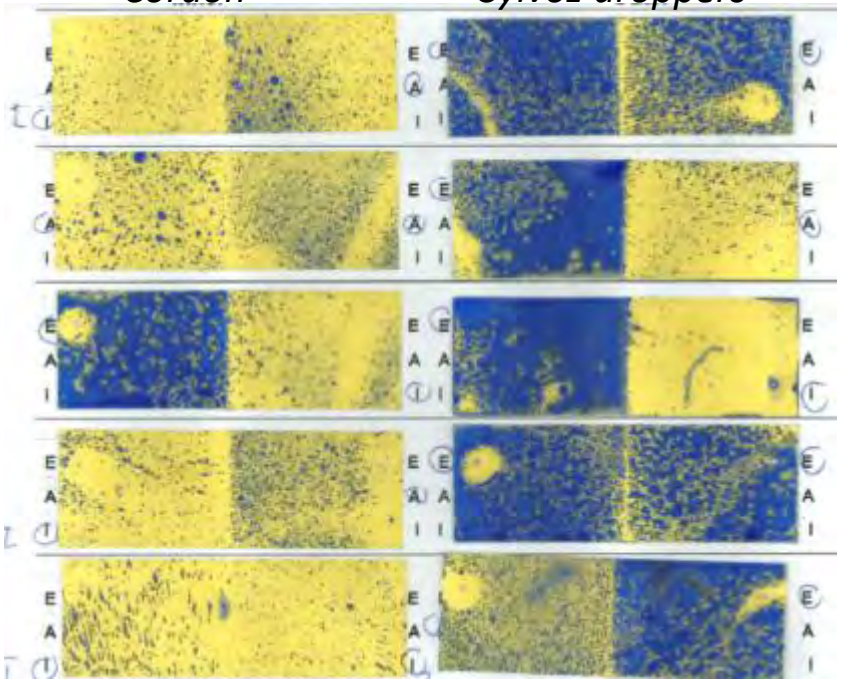
400 l/ha at PBC (30 Jan)
Open Merlot canopy
60% of output to bunch zone

Air assistance increased
Two extra nozzles in bunch zone

Coverage monitoring on a block that failed due to powdery mildew in 2014

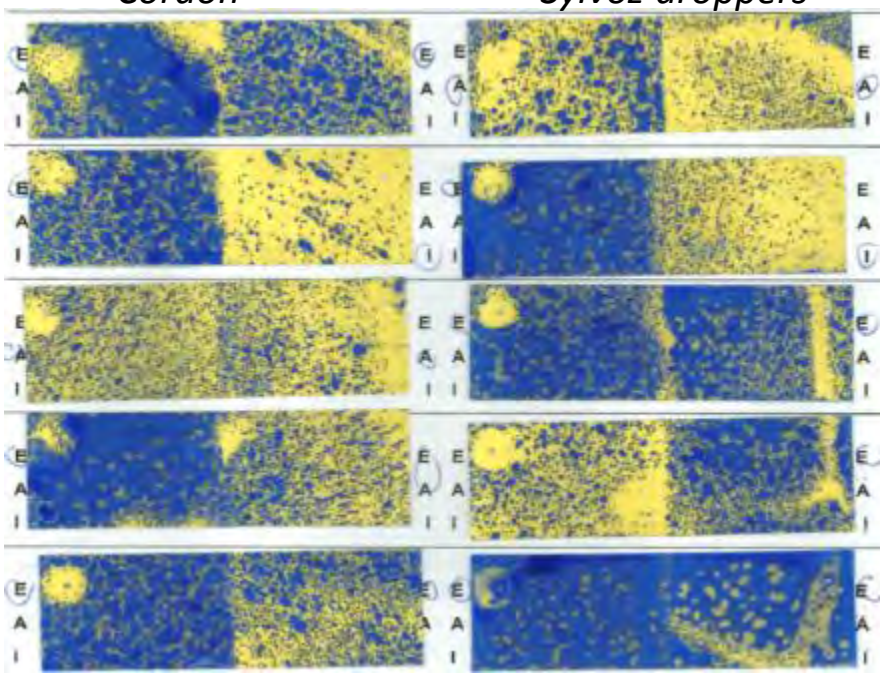
Even nozzle outputs

Cordon *Sylvoz droppers*



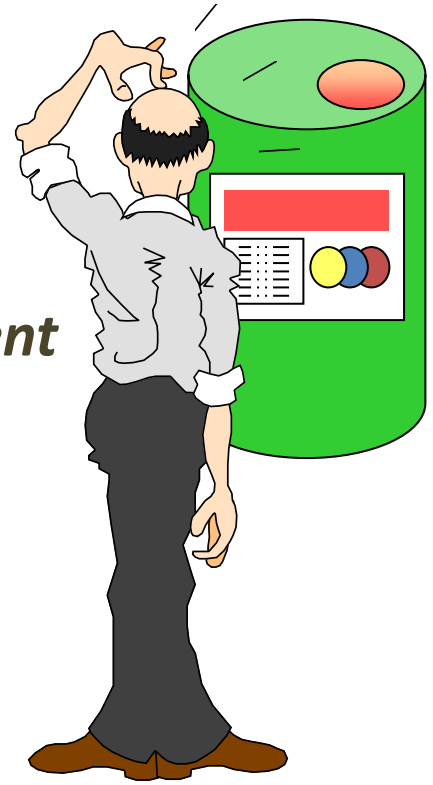
70% of output to bunch zone

Cordon *Sylvoz droppers*



What does all this mean for powdery mildew control?

- *A regular spring spray programme is essential to maintain protection for powdery mildew*
- *Sprayer setup is critical for spray retention and inner canopy coverage*
- *Think about product choice and application rates for efficacy and resistance management*
- *Need to increase chemical application rates (per ha) as row spacing decreases*



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PURE DISCOVERY

Rate Adjustment Tools

Calculate litre per 100 metre spray volume requirements to spray to runoff.

Defines dilute spray volumes.

Back calculate to get product per hectare required on different row Spacings.

But that was probably too complicated

Now promoting a row spacing based rate per hectare adjustment that works with all chemical label rate per 100 litre mixing requirements.

For FULL CANOPY sprays - Flowering onwards							
Row spacing (m)	**1.50**	**1.75**	**2.00**	**2.25**	**2.50**	**2.75**	**3.00**
	Litres per ha required to wet medium density canopies to runoff						
Label rate *g or ml/100 litres*	2000	1710	1500	1330	1200	1090	1000
	Required product application rate per hectare (*grams or mililitres per hectare*)						
1	**20**	**17**	**15**	**13**	**12**	**11**	**10**
	Required product application rate per hectare *(kilograms or litres per hectare)*						
10	0.20	0.17	0.15	0.13	0.12	0.11	0.10
50	1.00	0.86	0.75	0.67	0.60	0.55	0.50
100	2.0	1.7	1.5	1.3	1.2	1.1	1.0
150	3.0	2.6	2.3	2.0	1.8	1.6	1.5
200	4.0	3.4	3.0	2.7	2.4	2.2	2.0
250	5.0	4.3	3.8	3.3	3.0	2.7	2.5
300	6.0	5.1	4.5	4.0	3.6	3.3	3.0
500	10.0	8.6	7.5	6.7	6.0	5.5	5.0
1000	20.0	17.1	15.0	13.3	12.0	10.9	10.0

Sulphur (80% formulation)
Low rate = 150g/100L
High rate = 300g/100L

This approach can work for different spraying targets

For any approach to work we have to get consistent messaging from NZ Winegrowers, from wine companies, from regulators, from the chemical industry

For FULL CANOPY sprays - Flowering onwards

Row spacing (m)	1.50	1.75	2.00	2.25	2.50	2.75	3.00
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50	1.00	0.86	0.75	0.67	0.60	0.55	0.50
100	2.0	1.7	1.5	1.3	1.2	1.1	1.0
150	3.0	2.6	2.3	2.0	1.8	1.6	1.5
200	4.0	3.4	3.0	2.7	2.4	2.2	2.0
250	5.0	4.3	3.8	3.3	3.0	2.7	2.5
300	6.0	5.1	4.5	4.0	3.6	3.3	3.0
500	10.0	8.6	7.5	6.7	6.0	5.5	5.0
1000	20.0	17.1	15.0	13.3	12.0	10.9	10.0

For BUNCH LINE sprays - 70% of full canopy dose rate

Row spacing (m)	1.50	1.75	2.00	2.25	2.50	2.75	3.00
	Litres per ha required to wet medium density canopies to runoff						
Label rate *g or ml/100 litres*	1400	1200	1050	930	840	760	700
	Required product application rate per hectare (*grams or millilitres per hectare*)						
1	**14**	**12**	**11**	**9**	**8**	**8**	**7**
	Required product application rate per hectare *(kilograms or litres per hectare)*						
10	0.14	0.12	0.11	0.09	0.08	0.08	0.07
50	0.70	0.60	0.53	0.47	0.42	0.38	0.35
100	1.4	1.2	1.1	0.9	0.8	0.8	0.7
150	2.1	1.8	1.6	1.4	1.3	1.1	1.1
200	2.8	2.4	2.1	1.9	1.7	1.5	1.4
250	3.5	3.0	2.6	2.3	2.1	1.9	1.8
300	4.2	3.6	3.2	2.8	2.5	2.3	2.1
500	7.0	6.0	5.3	4.7	4.2	3.8	3.5
1000	14.0	12.0	10.5	9.3	8.4	7.6	7.0

Bud break to pre-flowering

Row spacing (m)	1.50	1.75	2.00	2.25	2.50	2.75	3.00
	Litres per ha required to wet medium density spring canopies to runoff						
Label rate *g or ml/100 litres*	1330	1140	1000	890	800	730	670
	Required product application rate per hectare (*grams or millilitres per hectare*)						
1	**13**	**11**	**10**	**9**	**8**	**7**	**7**
	Required product application rate per hectare *(kilograms or litres per hectare)*						
10	0.13	0.11	0.10	0.09	0.08	0.07	0.07
50	0.67	0.57	0.50	0.45	0.40	0.37	0.34
100	1.3	1.1	1.0	0.9	0.8	0.7	0.7
150	2.0	1.7	1.5	1.3	1.2	1.1	1.0
200	2.7	2.3	2.0	1.8	1.6	1.5	1.3
250	3.3	2.9	2.5	2.2	2.0	1.8	1.7
300	4.0	3.4	3.0	2.7	2.4	2.2	2.0
500	6.7	5.7	5.0	4.5	4.0	3.7	3.4
1000	13.3	11.4	10.0	8.9	8.0	7.3	6.7

NEW ZEALAND WINE
PURE DISCOVERY

- Enough for now thanks

Appendix 7. Barbara Hall

SOUTH AUSTRALIAN RESEARCH & DEVELOPMENT INSTITUTE
PIRSA

Fungicide resistance in Australian vineyards

Barbara Hall, Suzanne McKay 2015

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

SOUTH AUSTRALIA

Government of South Australia
Primary Industries and Regions SA

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Fungicide resistance

- History in Australian viticulture
- Project background
- The highs and lows
- Current status
- Addressing the issues

Fungicide resistance in Australian viticulture

Botrytis	Downy mildew	Powdery mildew
benzimidazoles	metalaxyl (4)	QoI (11)
dicarboximides (2)		DMI (3)
anilinopyrimidines (12)		metrafenone (U8)
QoI (11)	QoI (11)	boscalid – SDHI (7)
fenhexamid (17) ✓	phosphonates (33)	fenhexamid (17)
boscalid – SDHI (7) ✓	CAA (40)	azanaphthalenes (13)
cyprodonil (9)		spiroxamine (5)
		cyflufenamid (U6)
+4 (M, M1, M4, M5)	+5 (M1, M3, M4, M5, M9)	+3 (M, M1, M2)

known in Australia pre project

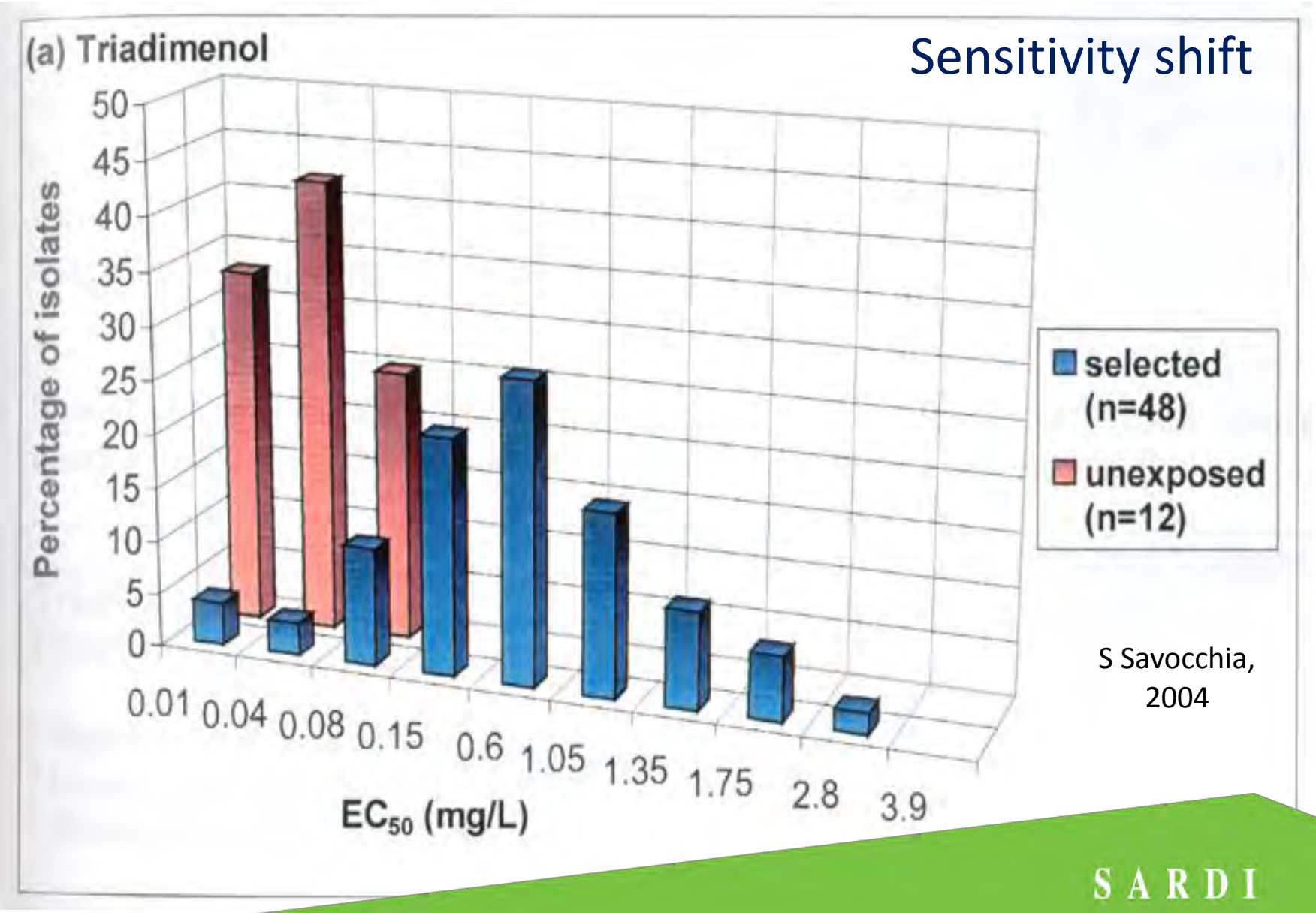
✓Confirmed in project

SARDI

DMI resistance - powdery

- Inhibitor of ergosterol synthesis
- Variations in the activity spectra of the different DMI fungicides
- Several resistance mechanisms are known incl. target site mutations in cyp51 (erg 11) gene, e.g. Y136F, (others known V136A, Y137F, A379G, I381V; cyp51 promotor; ABC transporters)
- “Qualitative” – sensitivity shift
- Probably widespread in Australia but controlled by increasing rates or changing product

DMI resistance - powdery



S Savocchia, 2004

SARDI

Strobilurin resistance - powdery

- Mitochondrial respiration inhibitor
- Target site mutation G143A, F129L
- “Quantitative” – all or nothing
- Sudden control failures
- New York 2002 appeared in multiple sites, 15-20 applications since registration
- Few problems if tank-mixed w/sulfur, even with >20 applications
- Registered in Aust ~2000: >20 applications?
- Resistance confirmed in Australia in 2010

Strobilurin resistance - powdery

Number of samples with mutated allele G143A in each frequency range (2011/12, 2012/13)

	0	1-25	25-50	50-95	>95	Total
Victoria	0	0	3	8	26	37
South Australia	4	2	3	2	31	42
Western Australia	0	2	0	1	6	9
Total	4	4	6	11	63	88

G. Stammler, BASF Germany
Nufarm

What is the incidence and severity of fungicide resistance in Australian vineyards?

Project 2013-2016

Australian Government
Australian Grape and Wine Authority

“Understanding fungicide resistance in viticulture”

Powdery mildew
(SARDI)

Botrytis bunch rot
(Curtin University, WA)

Downy mildew
(CSU, NSW)

SARDI

Australian Government
Australian Grape and Wine Authority

Project team and industry collaborators

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Curtin University

The Australian Wine Research Institute

Department of Agriculture and Food
GOVERNMENT OF WESTERN AUSTRALIA

NATIONAL Wine & Grape INDUSTRY CENTRE

Charles Sturt University

Nufarm

BAYER

THE UNIVERSITY of ADELAIDE

syngenta

Industry reference group

Accolade Wines

TREASURY WINE ESTATES

VITIBIT PTY LTD

WINE TASMANIA

WATERSHED PREMIUM WINES MARGARET RIVER
Awaken Your Senses

AHA viticulture

- Vitisolutions

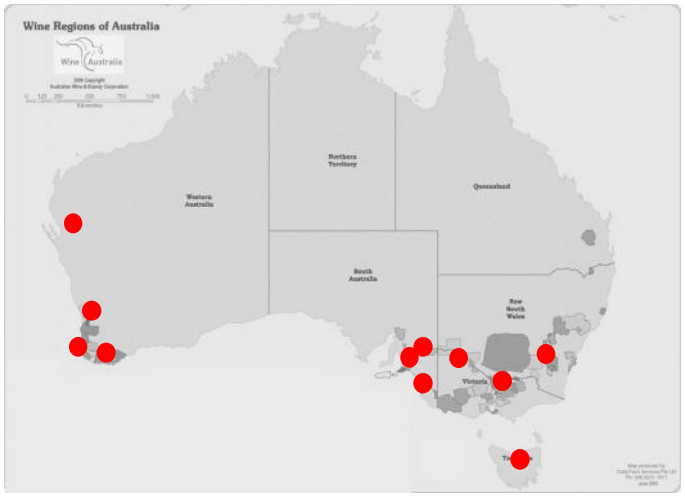
Aims

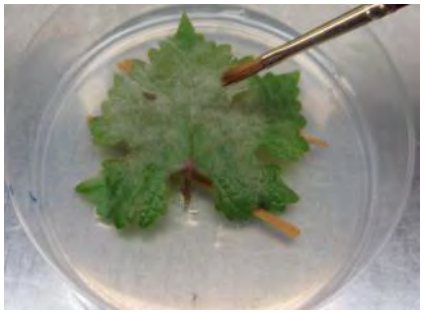
1. Determine incidence and severity of resistant populations
2. Develop a rapid and accurate test for detection and quantification of resistance using high-throughput next generation sequencing
3. Develop and validate effective and sustainable resistance strategies for the at-risk fungicides

Aims

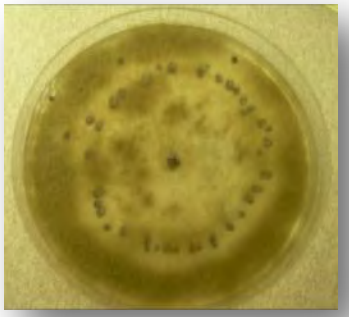
1. Determine incidence and severity of resistant populations
    - Develop an effective and reliable phenotypic testing method
    - Compare phenotypic with genotypic
2. Develop a rapid and accurate test for detection and quantification of resistance using high-throughput next generation sequencing
3. Develop and validate effective and sustainable resistance strategies for the at-risk fungicides

Approach

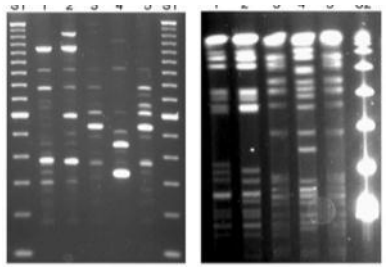




Downy / powdery



Botrytis



Genotype

+

Phenotype bioassay

Sensitive?

Resistant?

SARDI

Powdery mildew: The joys of working with biotrophs

The joys of working with biotrophs

1st Challenge – keeping a constant supply of young, healthy (and mildew free!) leaves:

- regular pruning
- regular feeding
- strict hygiene
- “soft’ fungicides weekly e.g. ecocarb

The joys of working with biotrophs

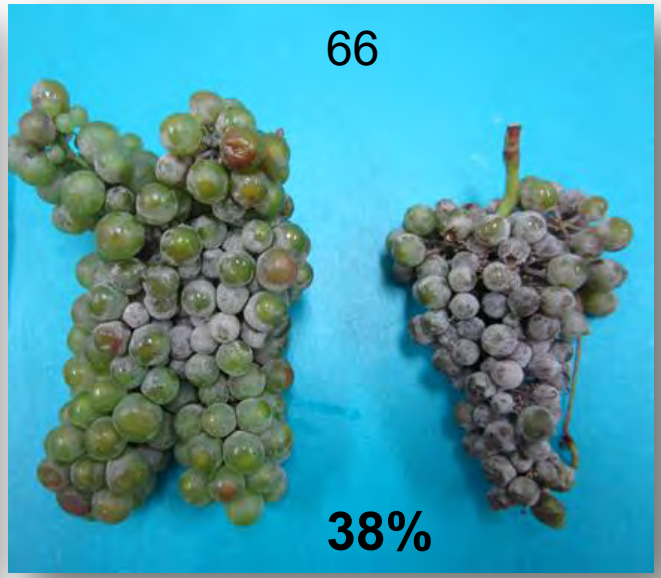
2nd Challenge – keeping the detached leaves alive:

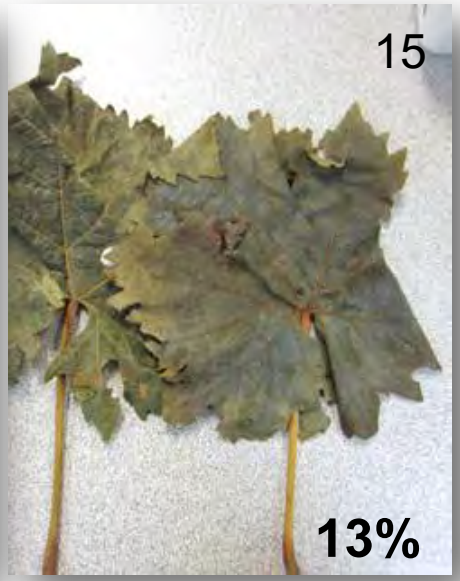
Success!

- Young Cabernet Sauvignon leaves
- Petri dishes 90mm, 16mm high
- 1.5% WA with pimaracin (2.5 µl/ml)
- Stem into agar, leaf on tooth picks

The joys of working with biotrophs

3rd Challenge – getting cultures growing from field samples:





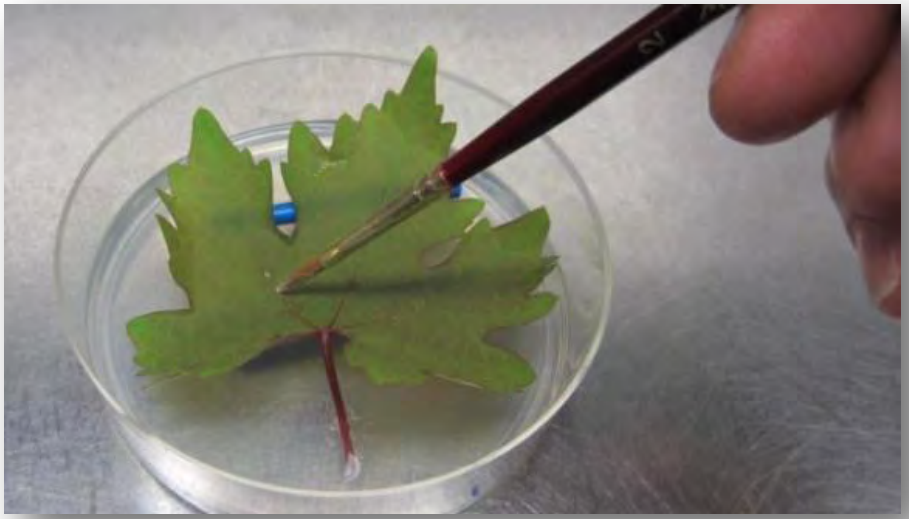
4th Challenge – getting growers to send in suitable samples suitably packaged!

The joys of working with biotrophs

5th Challenge – keeping the mildew viable and free of contamination:

Cultures maintained on sterilised detached leaves

Transfer to fresh leaves every week (multi spore)



Ideally - tissue culture?

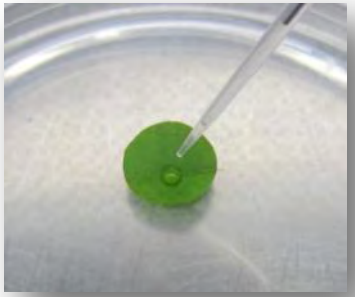
The joys of working with biotrophs

Final challenge – getting a test method that works reliably and repeatedly:

Leaf material: plantlets, whole leaf, leaf disc?

Fungicide application: spray or soak?

Fungus application: spray, water drop or dry spore?



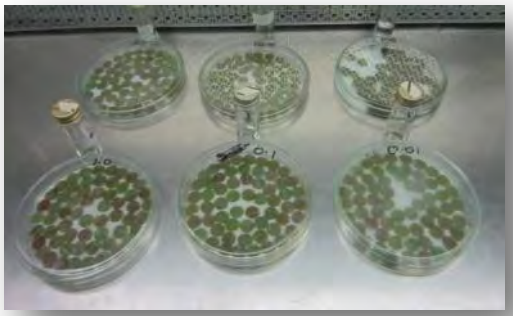
Culture establishment

Place spore onto sterilised leaf: work in laminar flow to ensure sterility

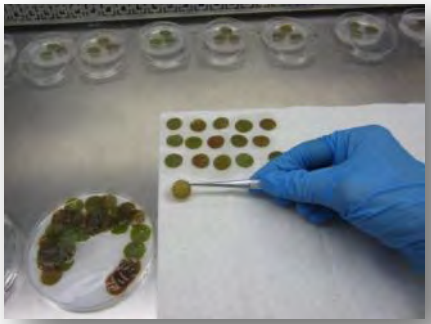
Single spore collection: Sable hair paint brush with all but 1 bristle removed

Keep leaf healthy for 10-14 days until colony grows

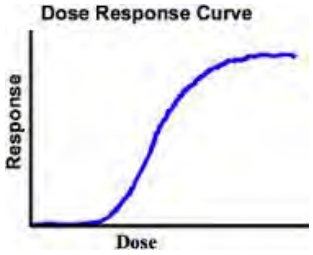
Phenotyping powdery



QoI (Cabrio) or DMI (Topas)



Inoculate: cotton bud from infected leaf to leaf disc



Probit analysis:
EC_{50} (µg/mL)

EC_{50} = effective concentration that inhibits 50% of maximal growth

SARDI

Results

Botrytis

State	Number of sites tested	Number of sites with reduced sensitivity			
		Filan®[1]	Teldor®[2]	Rovral®[3]	Scala®[4]
Western Australia	31	7	0	9	9
New South Wales	11	1	0	1	1
Victoria	4	3	1	2	4
South Australia	3	0	0	0	0
Queensland	1	0	0	0	0
Tasmania	1	0	0	1	0
Total	51	11 (22%)	1 (2.0%)	13 (16%)	14 (28%)

- Filan® (boscalid): EC_{50} = >3 µg/mL and/or MIC = >5 µg/mL
- Teldor® (fenhexamid): EC_{50} = >20 µg/mL and/or MIC = >5 µg/mL
- Rovral® (iprodione): EC_{50} = >5 µg/mL and/or MIC = >10 µg/mL
- Scala® (pyrimethanil): EC_{50} = >0.8 µg/mL and/or MIC = >25 µg/mL

Botrytis – multidrug resistance

State	Number of sites tested	Number of sites with multiple resistance*				
		0	1	2	3	4
Western Australia	31	17	6	5	3	0
New South Wales	11	9	1	1	0	0
Victoria	4	0	1	1	1	1
South Australia	3	3	0	0	0	0
Queensland	1	1	0	0	0	0
Tasmania	1	0	1	0	0	0
Total	51	30 (59%)	9	7	4	1

* number of sites with all sensitive isolates (0) or reduced sensitivity to one (1), two (2), three (3) or four (4) fungicide groups

Botrytis – summary

- Boscalid and fenhexamid resistance detected
- Novel Bos-1 (iprodione) and Cgs (pyrimethanil) mutations found
- Good correlation between phenotyping and genotyping results
- Multi single-site resistance (MSSR) present in a number of isolates

Powdery – 2013/4 phenotyping results

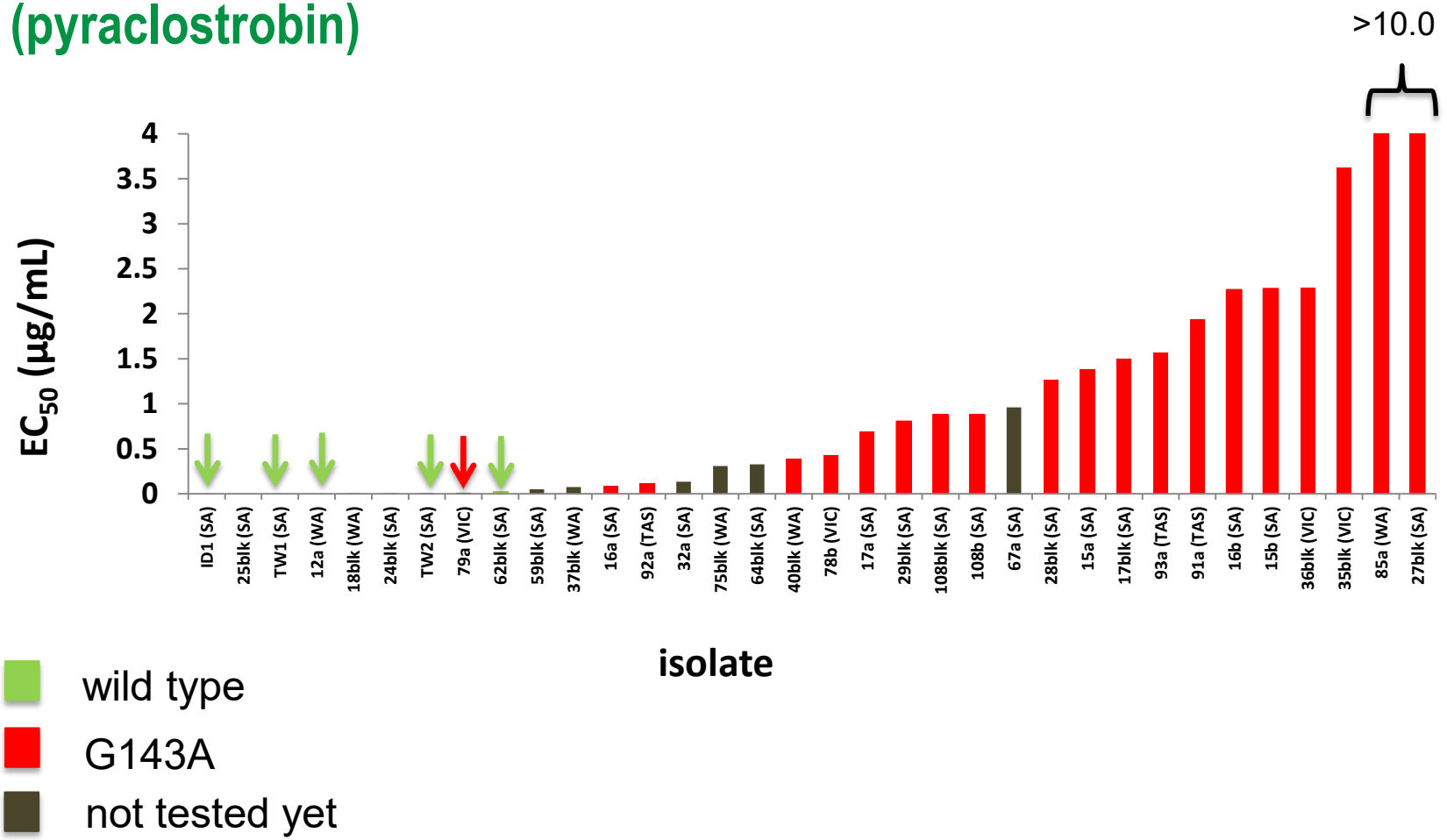
	Cabrio®		Topas®	
	Number of sites tested	No. reduced sensitivity[1]	Number of sites tested	No. reduced sensitivity[2]
South Australia	32	10	28	7
Western Australia	8	4	10	2
Victoria	3	2	3	2
New South Wales	1	0	1	0
Tasmania	3	2	3	0
TOTAL	47	18 (38%)	45	11 (24%)

1. Cabrio® (pyraclostrobin): EC_{50} >0.5 µg/mL
2. Topas® (penconazole): EC_{50} >0.25 µg/mL

Genotyping powdery – known mutants

- Triazoles DMIs: cyp51 gene
  - Y136F, Y137F and others
- QoI – strobilurins: cytb gene
  - G143A, F129L
- Others?

QoI phenotype vs genotype: Cabrio®
(pyraclostrobin)



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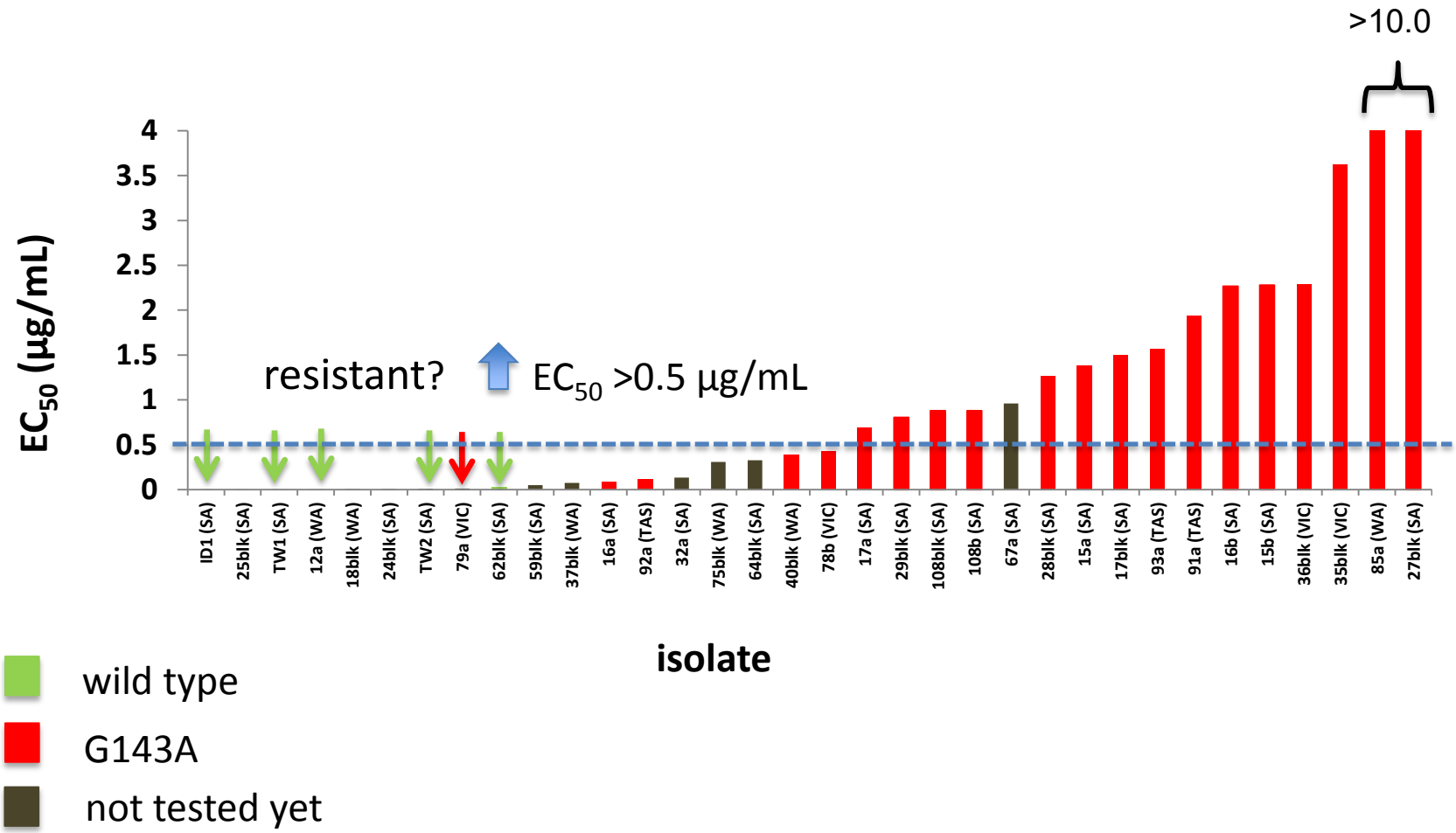
QoI phenotype vs genotype: Cabrio®



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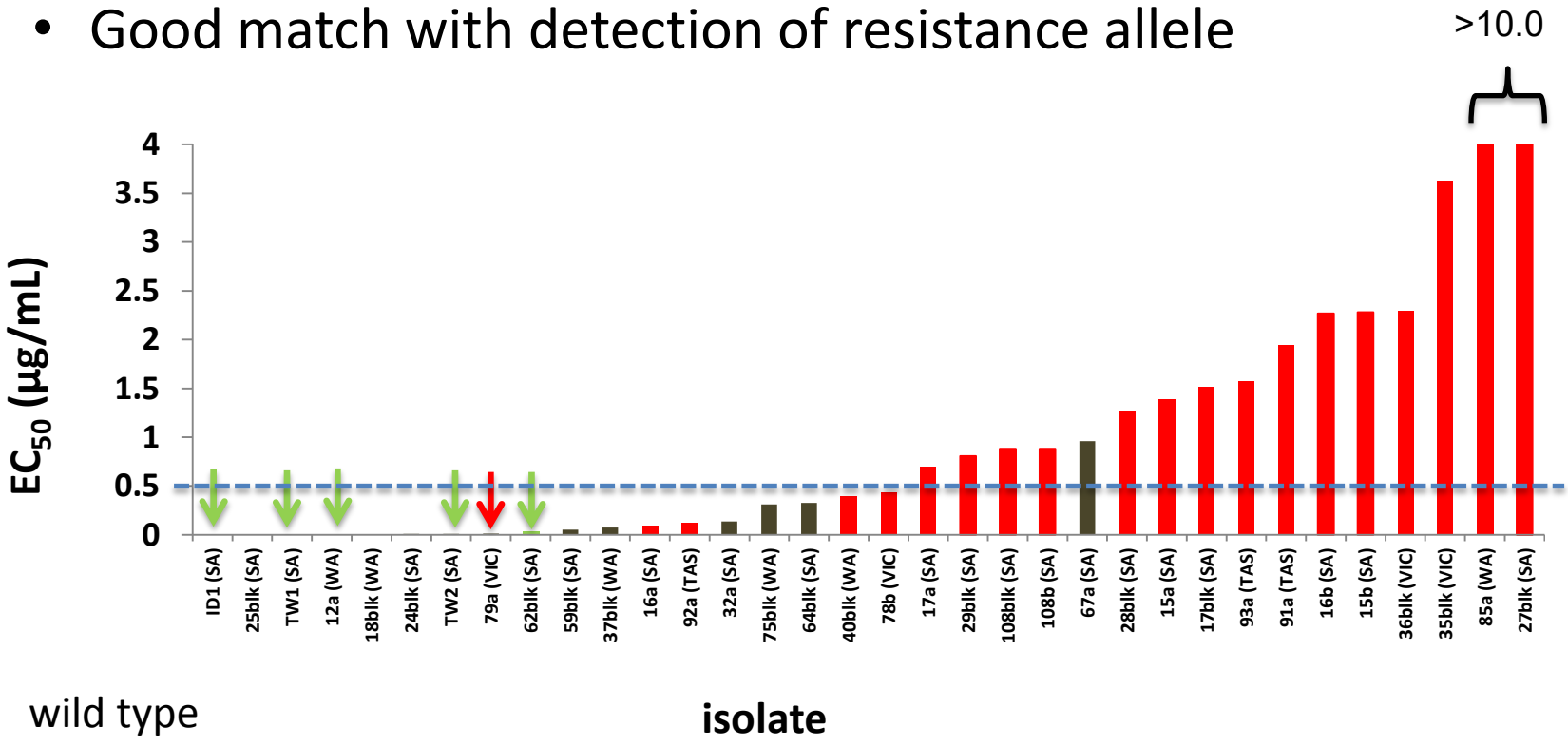
QoI phenotype vs genotype: Cabrio®

- Resistant phenotypes present
- Good match with detection of resistance allele



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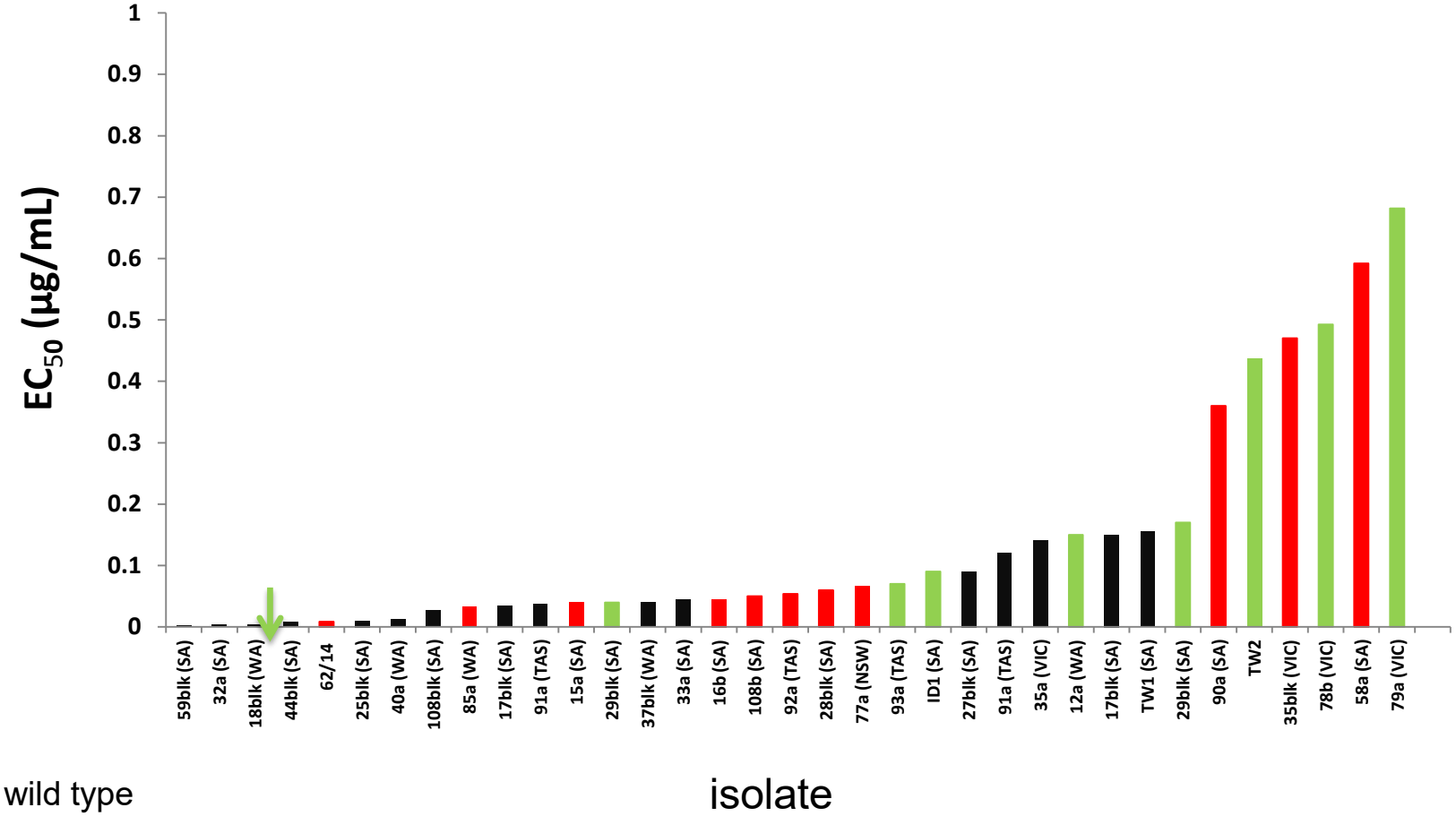
DMI phenotype vs genotype: Topas® (penconazole)



wild type

Y136F

not tested yet

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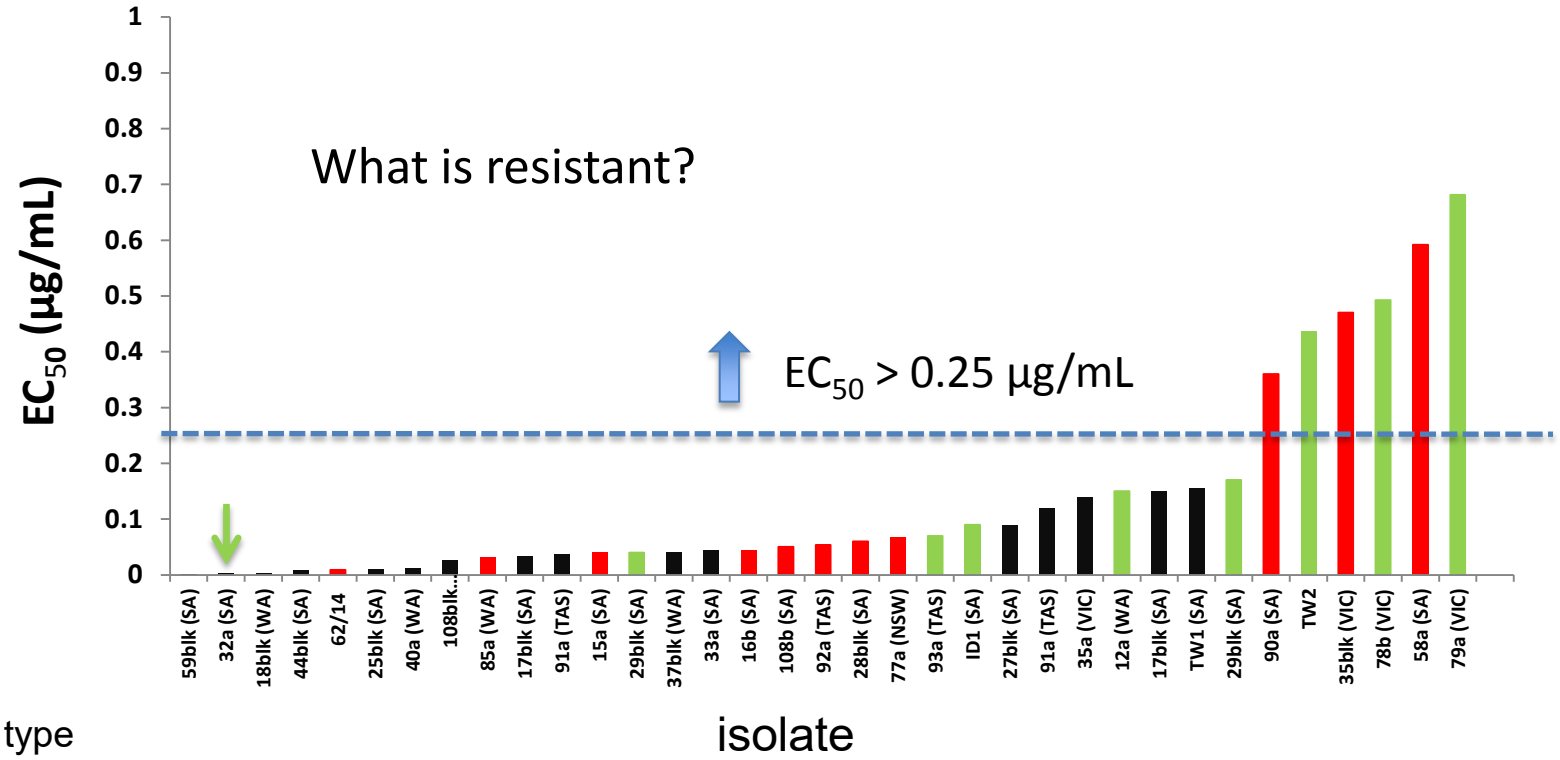
DMI phenotype vs genotype: Topas®

- Presence of resistance allele ≠ lack of disease control



wild type

Y136F

not tested yet

S McKay, SARDI

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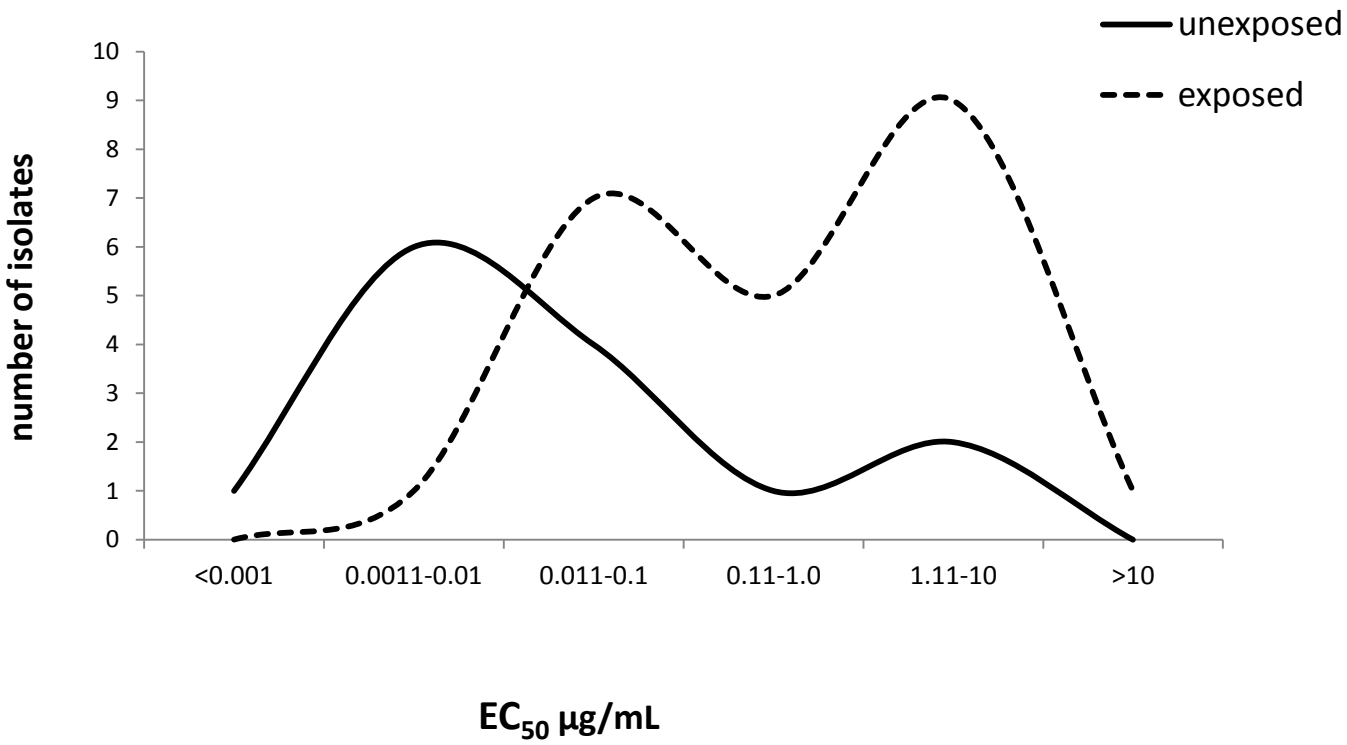
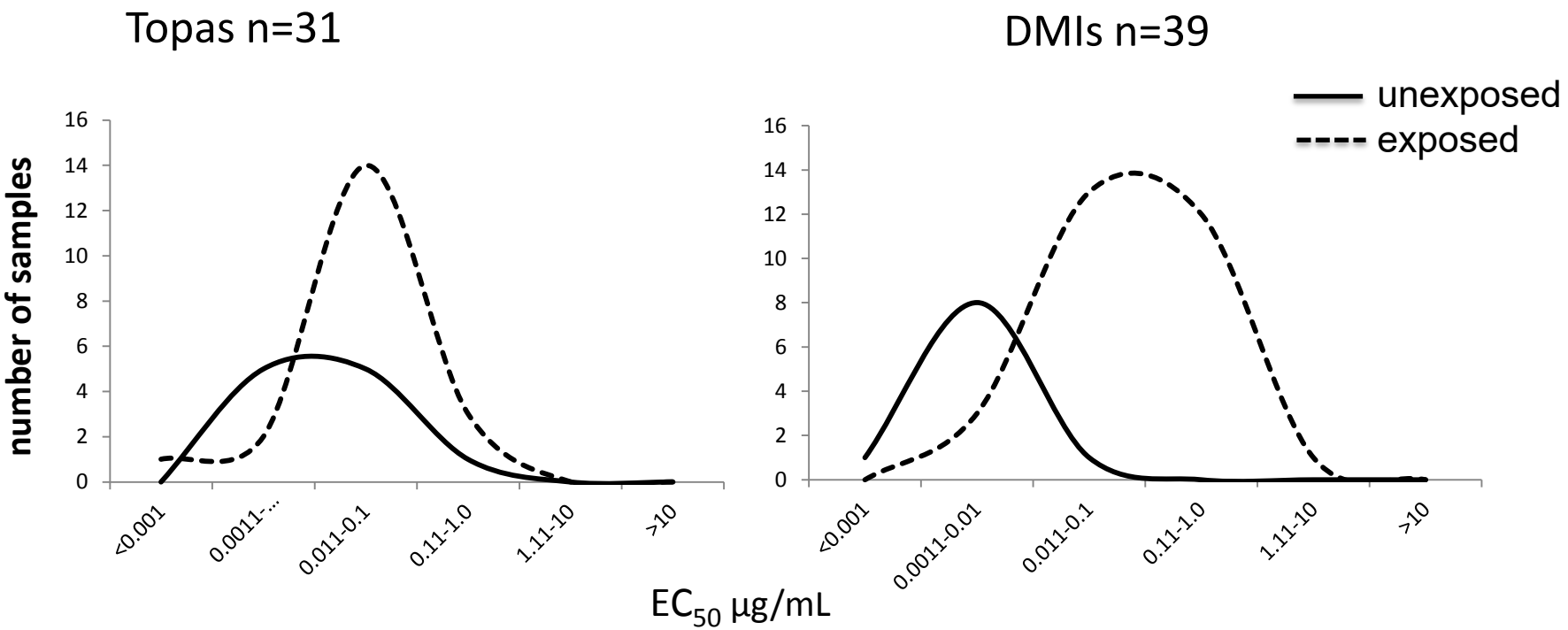
Sensitivity profiles: phenotype

Exposure to QoIs within the last 2 years (n=37)



Sensitivity profiles: phenotype

Exposure within the previous 2 years



Evidence of cross resistance?

Summary – powdery mildew & QoI

- Resistant populations present and widespread
  - 38% (n=47) with a EC_{50} of 0.5µg/mL
- Linked with presence of mutant
- Correlated to exposure over last 2 years

Summary – powdery mildew & DMI

- Resistant genotypes present
- Phenotype – reduced sensitivity (24% n=45)
- Reduced sensitivity not linked to single mutant

but

- Reduced sensitivity linked to exposure

- More testing needed!!

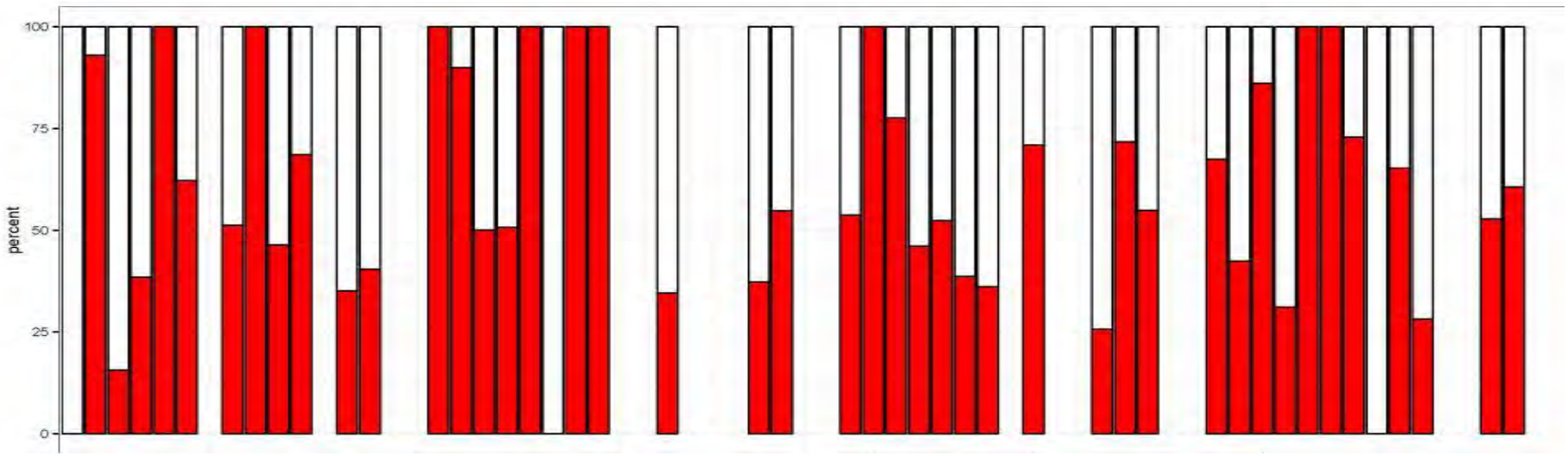
Issues

- Getting samples
- Working with obligate parasites
- Do we know all the mutants?
- How even is the spread of resistance over a vineyard?
- What levels will result in field failure?

Addressing the issues

- Getting samples:
  - actively targeting areas so far not covered
  - “meth lab” technique in biosecurity risk areas
- Working with obligate parasites:
  - streamlining the processes to achieve more:
  - pre screening with discriminatory doses = more fungicides tested?
  - but what dose to use?
- Unknown mutants: - High throughput, whole genome testing
- Spread of resistance over a vineyard: - Preliminary population studies – 50 - 100 subsamples per vineyard
- What levels will result in field failure: - ?????

Population studies – mutant frequency



Percent mutant present	0	1-25%	26-50%	51-95%	>95%
No. samples	4	4	24	30	13

(No DNA in 24)

and ultimately……

For illustration only!!!!

SARDI


WESTERN AUSTRALIA
SOUTH AUSTRALIA
Perth
Brisbane
Sydney
Great Australian Bight
ACT
Melbourne
Auckland
New Zealand

SARDI

Acknowledgements

- Data
  - S McKay, SARDI
  - L Harper, F Lopez, Curtin Uni WA
  - S Savocchia, PhD Adelaide Uni, now CSU NSW
- Project team and collaborators
- Growers and industry reps for samples
- AGWA

Thanks

M. Ayres

Appendix 8. Rob Beresford

The New Zealand Institute for Plant & Food Research Limited

Determining PM resistance to at-risk fungicides in NZ

Rob Beresford, Peter Wright, Peter Wood and Rob Agnew

Fungicide resistance in grapevine powdery mildew (*Erysiphe necator*)

- Evidence for development of resistance in powdery mildew in New Zealand is currently anecdotal

- However, resistance development in this pathogen is almost certain, given its track record overseas.

Impacts of resistance

- Worse disease epidemics in high-risk seasons
- Speculation about, and loss of confidence in, products that may be losing efficacy
- Potential litigation from concerns that products may have failed

- Reduced choice of fungicide products and loss of flexibility in spray programmes
- Cost and difficulty of finding new fungicide chemistry to use
- Costs to the wine industry in re-designing spray programmes to achieve disease control and avoid chemical residues.

How does resistance develop?

- Resistance arises from repeated use of certain fungicides with site-specific modes of action

- The fungus changes genetically allowing it to survive in the presence of the fungicide

- Resistance affects related products in the same **mode of action** group. Where there are several products in the same group, they may all be affected by the same genetic change to resistance.

PM resistance risk for different fungicide groups

Fungicide Resistance Action Committee (FRAC) classification (Europe)

Fungicide mode of action group	Resistance risk classification	Period of use in NZ (years)
Demethylation inhibitor (DMI)	Medium	>30
Quinone outside inhibitor (QoI; strobilurin)	High	~15
Azanaphthalene (AZN)	Medium	<5
Amine (morpholine)	Low-Medium	<5
Phenyl-acetamide	Not classified	<1

Which powdery mildew products are at risk?

Group (Medium risk)	**Fungicide active ingredient**	**Example products**
Demethylation inhibitor (DMI)	triforine	Saprol®
	myclobutanil	Systhane®, Prostar™, Validus®
	penconazole	Topas®
	cyproconazole	Alto®

Mode of action (MOA): Inhibit cell wall biosynthesis (curative)

Gradual loss of efficacy as resistance develops

Current guideline – max. 2 applications (4 if mixed).

Which powdery mildew products are at risk?

Group (High risk)	**Fungicide active ingredient**	**Example products**
Quinone outside inhibitor (QoI or strobilurin)	azoxystrobin	Amistar® WG
	pyraclostrobin	Cabrio® Pristine® (with boscalid)
	trifloxystrobin	Twist®, Protiva®

MOA: Inhibit cell respiration (protectant)

Rapid and complete loss of efficacy in many pathogens

Current guideline – max. 3 applications.

Which powdery mildew products are at risk?

Group (Medium risk)	**Fungicide active ingredient**	**Example products**
Azanaphthaline	quinoxyfen	Quintec®, Proxima®
	proquinazid	Talendo®

MOA: Inhibit cell signal transduction (protectant)

No current NZ guideline (resistance known overseas in *E. necator*).

Which powdery mildew products are at risk?

Group (Low-medium risk)	**Fungicide active ingredient**	**Example products**
Amine (morpholine)	spiroxamine	Spiral®, Impulse®

MOA: Inhibit cell wall biosynthesis (curative & protectant)

Current guideline – max. 3 applications (supplier recommendation).

Which powdery mildew products are at risk?

Group (not classified)	**Fungicide active ingredient**	**Example products**
Phenyl-acetamide	cyflufenamid	Flute®

MOA: Unknown (protectant)

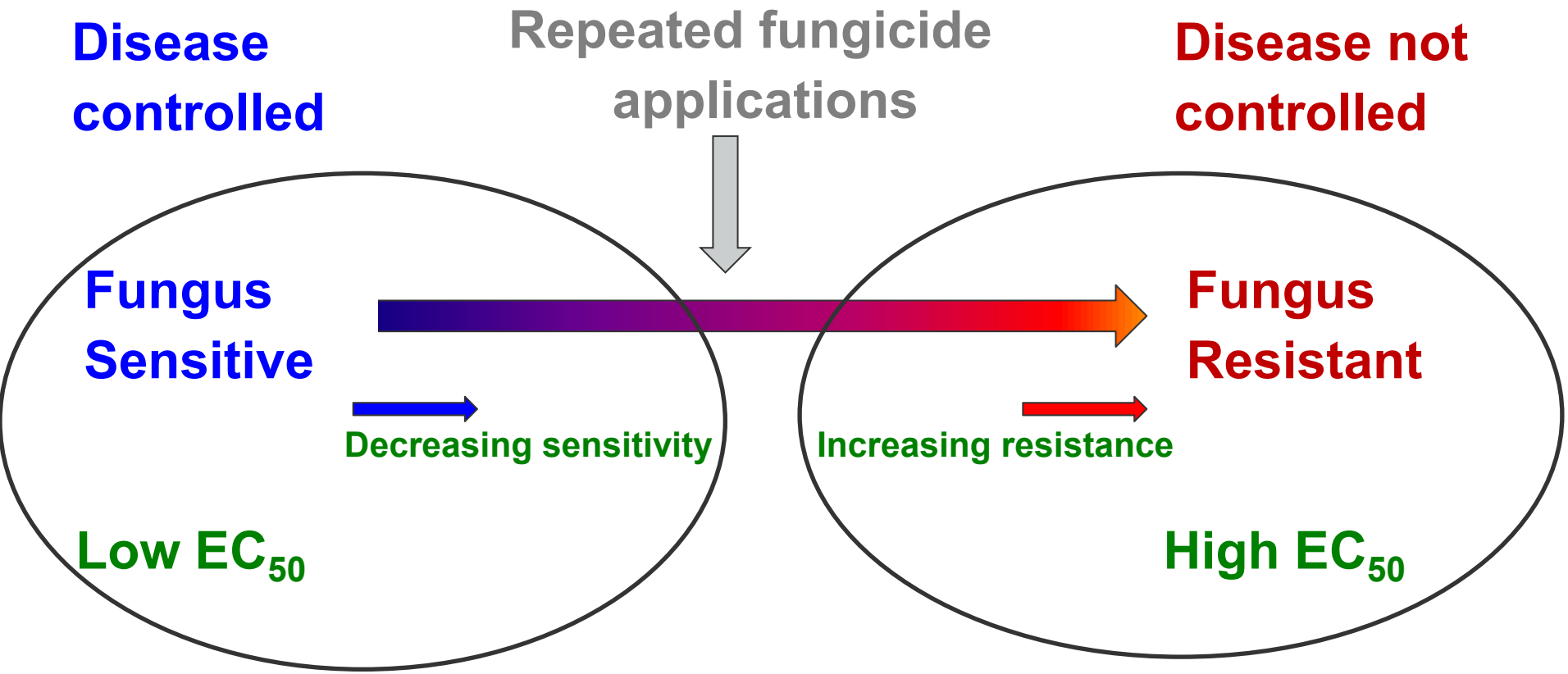
Current guideline – max. 2 applications (supplier recommendation).

NZ data about the at-risk groups?

- DMIs - a small New Zealand study in 1992 identified baseline sensitivity <0.3 mg/litre for one DMI active ingredient (triadimenol)

- Other groups used for PM – no information in NZ.

Studying fungicide resistance



EC_{50}= Effective concentration of fungicide that gives 50% inhibition

(Fungus tested at a range of fungicide concentrations)

Working with *E. necator*

- This fungus cannot be cultured on agar
- A plant assay system is needed.

Working with *E. necator*

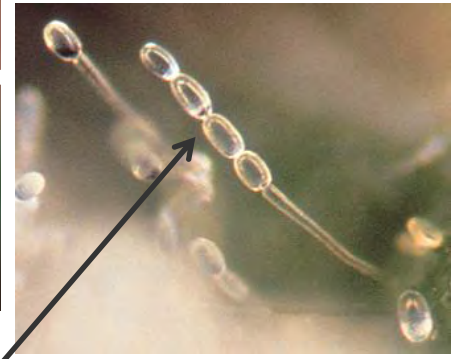
Peter Wright (PFR Pukekohe) has adapted overseas test methods to investigate powdery mildew resistance in NZ.

Working with *E. necator*

Powdery mildew-infected leaf collected from the vineyard

Isolating *E. necator* into culture

Powdery mildew-infected leaf collected from the vineyard



A single conidial chain or a single lesion removed and isolated into culture on a detached leaf.

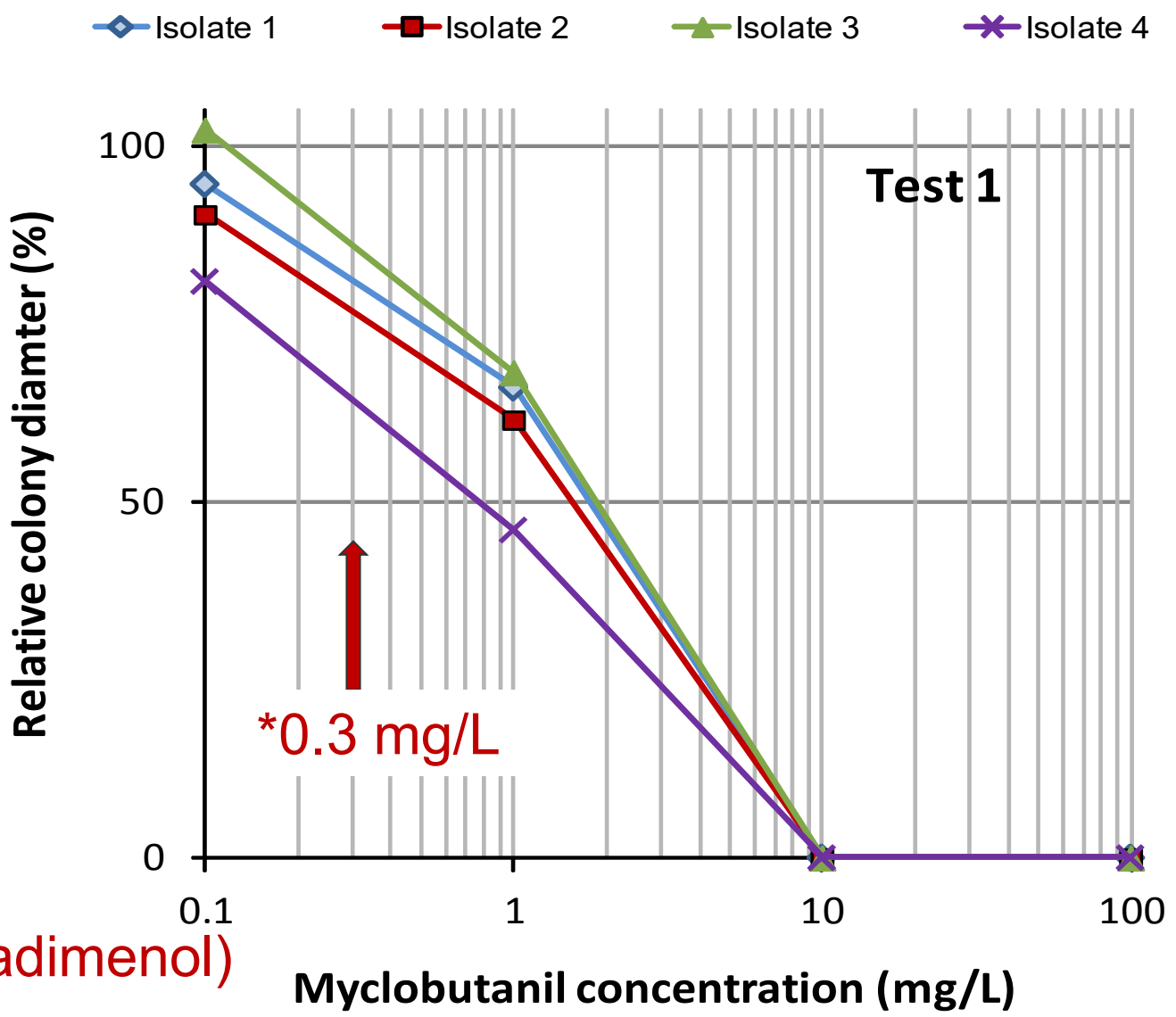
Fungicide resistance assay

- Test leaves are dipped in different concentrations of fungicide.

Test method development

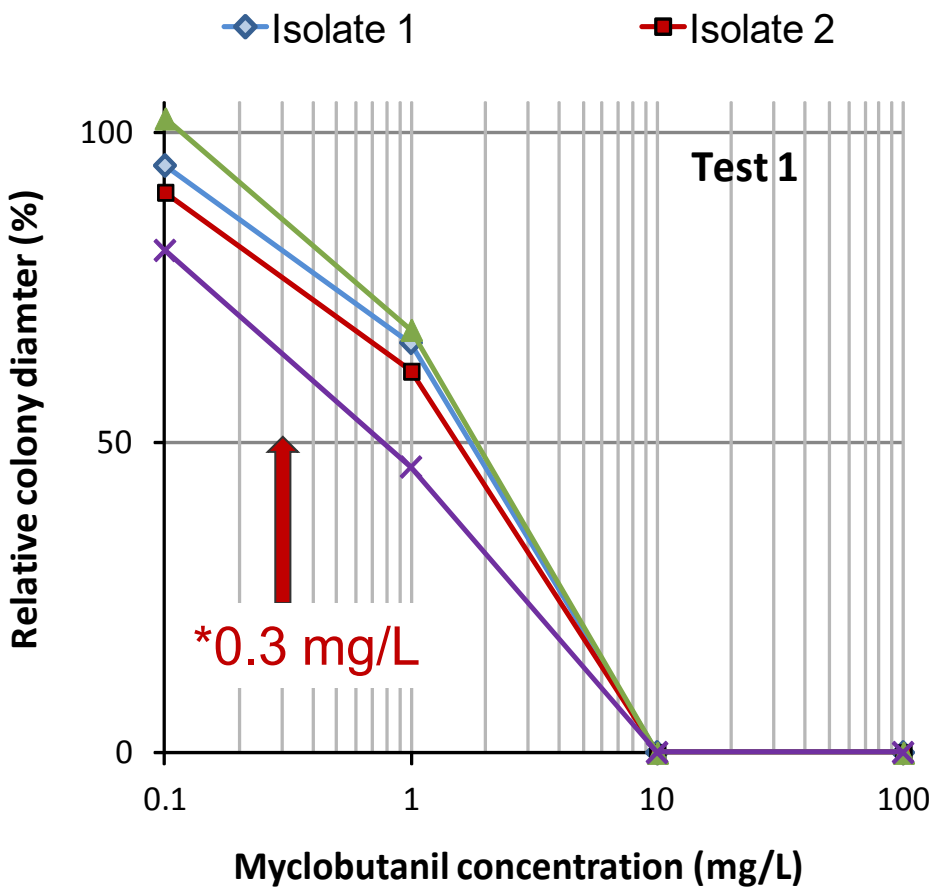
- Four isolates collected from a Hawke's Bay vineyard at the end of the 2013-14 season
- Range of fungicide test concentrations for EC_{50} were estimated from published literature
- Dipped and inoculated test leaves were incubated for 20 days
- Diameter of the sporulating part of the colony measured
- Relative growth = (dia_{fung_trt}) / $(dia_{control})$.

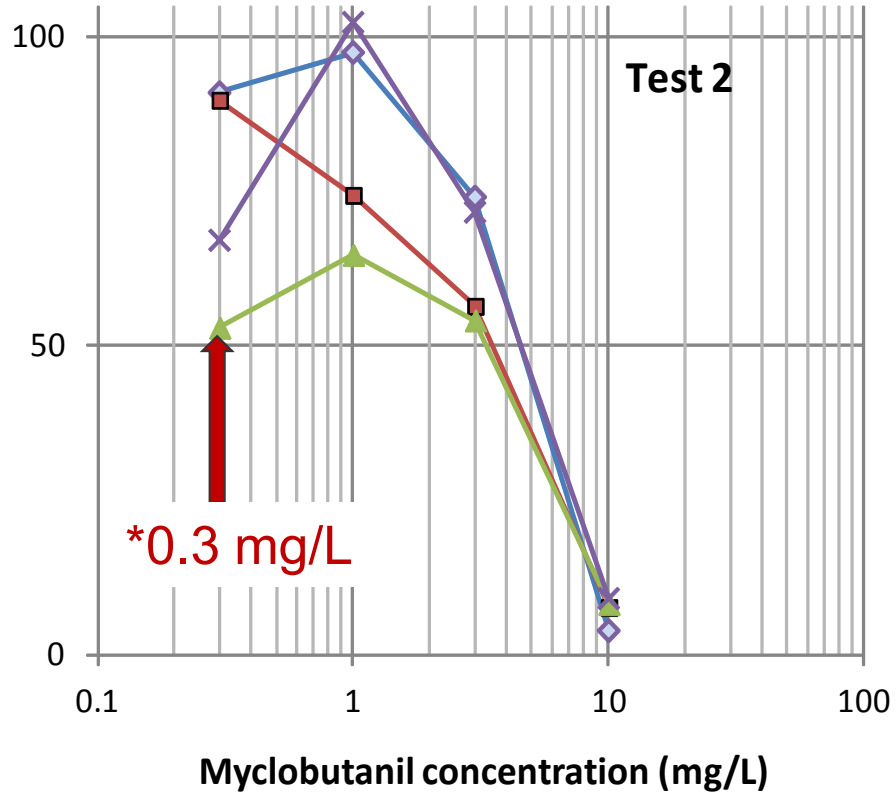
Inhibition of *E. necator* by myclobutanil (Systhane®)



*Baseline (triadimenol) - NZ 1992

Myclobutanil EC_{50} estimates for tests1 and 2





*Baseline (triadimenol)
- NZ 1992

EC50	Isolate				
	1	2	3	4	Mean
Test 1	1.7	1.5	1.8	0.8	1.5
Test 2	4.4	3.3	3.2	4.4	3.8

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Conclusions

- Preliminary myclobutanil EC_{50} > 1 mg/L is consistent with a shift towards resistance having occurred (only 4 isolates from Hawke's Bay).
- Further method development needed to improve repeatability of the method
- Wider survey is under way
- There are new fungicide groups available, although their resistance risk needs to be monitored and managed.

Next steps

- Resistance to DMIs is probably developing, but are all three active ingredients (myclobutanil, penconazole and cyproconazole equally affected? Which ones are affected and which ones are still useful?
- Nation-wide vineyard survey to determine *E. necator* DMI and QoI sensitivity (Project under discussion with NZW)

Thank you

Appendix 9. George Follas

New Zealand Plant Protection Society (Inc)

NZCPR
New Zealand Committee on Pesticide Resistance

The main advocacy group for pesticide resistance management in New Zealand

George Follas

Who are the NZCPR?

Task Group Coordinators:

Fungicides	Grant Hagerty	*BASF New Zealand Ltd*
Herbicides	Kerry Harrington	*Massey University*
Insecticides	Tim Herman	*Pipfruit New Zealand*

Chair. : George Follas *Etec Crop Solutions Ltd*

Science advisor : Rob Beresford *Plant & Food Research*

NZCPR functions

1) Advocacy

2) Three Task Groups

a)fungicides/bactericides
b)insecticides/ miticides
c) herbicides

3) Develops and publishes Strategies/guidelines

for resistance management

Freely available on the NZPPS website (www.nzpps.org)

Information on resistance management is placed on product labels.

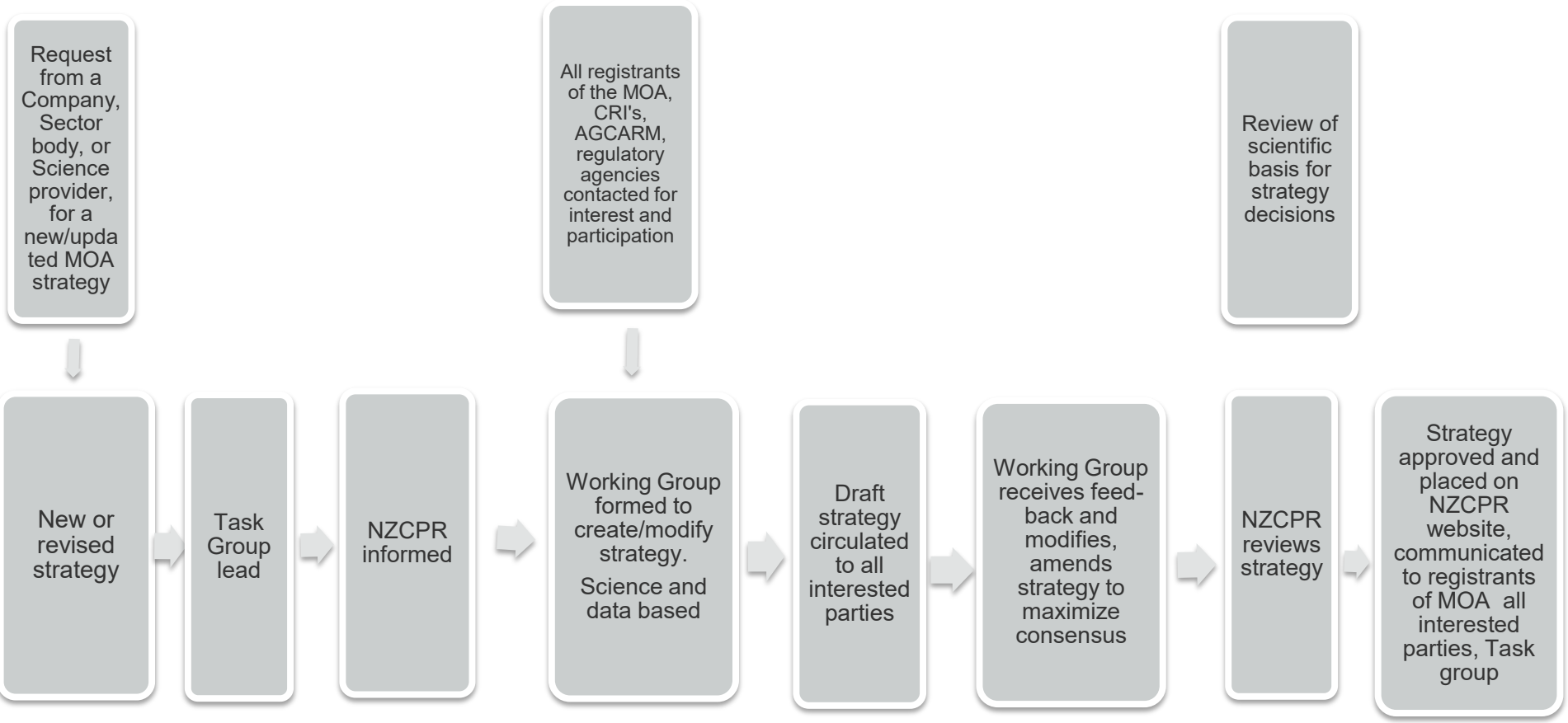
A little History

1982 Pesticide Resistance seminar Proceedings NZPPS
1987 NZCPR First formed
1988 Phenylamide strategy
1994 Herbicides Triazine/Phenoxy/Sulfonylurea strategy
1996 Insecticides GPA/Leafhopper/Leafroller/mealybug/spider mites/thrips/TFM/Whitefly Fungicides – Benzamidazole, CAA /DMI/ Dicarboximide / Dodine / Morpholine strategy
1996 NZPPS Pesticide Resistance Prevention and Management
1997 Melon aphid strategy
1999 Anilopyrimidine/Phenylamides/QoI strategy
2000 DBM strategy
2002 Lettuce aphid strategy
2003 Pesticide resistance information placed on NZPPS website.
2003 DMI / Dicarboximide strategy revised
2004 Insecticides GPA/Leafhopper/Leafroller/Lettuce aphid/mealy bug/ melon aphid/spider mites/TFM , Fungicides- Anilopyrimidine/ Benzamidazole/ Dodine/ Morpholine/ Phenylamides/CAA strategy revised
2005 QoI strategy revised
2005 Thrips/Whitefly strategy revised
2005 NZPPS, PESTICIDE RESISTANCE: Prevention and Management Strategies 2005
2005 Reactivation of task groups for Herbicides, Insecticides and Fungicides.
2006 NZCPR renewed
2007 CAA strategy revised
2011 SDHI strategy /Streptomycin strategy revised
2012 DBM strategy revised
2013 *Venturia inaequalis* strategy
2014 MOA charts updated, some strategies updated
2014 Sustainable Wine Growing, grape botrytis AP strategy strategy revised
2014 Summerfruit NZ, on behalf of NZCPR, with a resistance management wall chart
2014 Glyphosate strategy, Anilopyrimidine Grapes strategy, 2014 Maize weeds
2015- Cereal fungicide strategy revision. PM grapes?

Resistance Management 101

1. Understand the pest
2. Use the right product at the right time
3. Follow the label
4. Know the **mode of action**
5. Follow the **strategy**
6. Monitor/Survey the situation
7. Adjust the strategy based on the monitoring
8. Keep as many Modes of action

Strategy development process



Strategies

a) **New Zealand Plant Protection Society**

   coordinating strategies for preventing and managing pesticide resistance in cropping systems since 1987, through the NZCPR

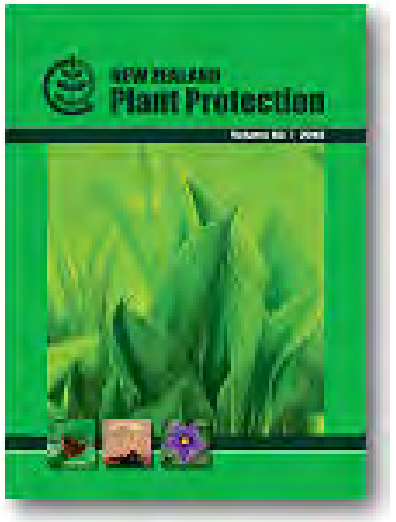
b) **Strategies written by Task groups**

c) **ACVM require MOA and resistance statements on labels**

d) **Industry must use the strategies**

How to access Strategies

Resistance strategies **published regularly** in the Society's journal, *New Zealand Plant Protection*



Martin N.A., Beresford, R.M., Harrington K.C. (2005)
Pesticide resistance: prevention and management strategies 2005.
New Zealand Plant Protection Society Inc: 166 p.

Bourdôt G.W., Suckling D.M. (1996)
Pesticide resistance: prevention & management.
New Zealand Plant Protection Society Inc: 225 p.

Easiest access

www.nzpps.org

Pesticide Resistance Strategies

New Zealand Plant Protection Society (Inc)

Home | Herbicides | Insecticides & miticides | Fungicides & bactericides | Crops

Introduction to pesticide resistance management

What is pesticide resistance?

Among the billions of individuals that make up a pest population (be it disease, insect, mite, weed etc), there may exist some individuals that are less susceptible a pesticide than others. If the same pesticide is continually applied, then the more susceptible individuals will be killed, leaving only resistant individuals to breed and multiply. If the resistance is heritable then eventually a large proportion of the population may be resistant to the pesticide. The resistant pests may then cause unacceptable damage to crops.

Therefore, pesticide resistance or, more accurately, the resistance of pests to pesticides occurs **where the pest population has changed genetically so that it is less susceptible or sensitive to a pesticide or class of pesticides**. This means that a higher dose of pesticide is now required to control the pest population, or even that the highest practical dose will not kill all pest individuals.

Types of resistance

There are two types of resistance (or susceptibility) to pesticides:

1. the normal variability in the susceptibility of individuals of a population to a chemical control, and
2. changes in the overall susceptibility of pest population in response to exposure to a chemical.

Here, we are concerned with the latter, in which pesticides fail due to genetic change in the pest population, rather than changes in the crop plant or chemical.

Pesticide mode of action

- An active ingredient blocks a biochemical pathway in the pest's metabolism and prevents the pest from functioning normally

- The particular pathway that is blocked is the **mode of action (MOA)**

- Although MOAs are obviously different for herbicides, fungicides and insecticides, the strategies for resistance management are quite similar for all three groups

Prevention & management

Resistance management strategies involve **reducing exposure** of the pest in three ways:

1. Stop using the pesticide (may be difficult)

2. Reduce the frequency of use (alternate with a different MOA)

3. Reduce selection pressure by using it in combination with a pesticide that is not at risk (mixing with a different MOA)

Prevention & management

The strategy is to **minimize exposure:**

1. Reduce the frequency of use (alternate with a different MOA)

2. Reduce selection pressure by using it in combination with a pesticide that is not at risk (mixing with a different MOA)

3. **Follow the strategy**

Cross-resistance

- When a new type of MOA is introduced there is usually a proliferation of related (improved) products

- If resistance develops to one product, then the same resistance will probably affect all the related ones. These related chemicals form a **"mode" of action or "cross-resistance group"**

- Growers need to know whether the different products they can buy are in the same or different cross-resistance groups (can't tell from product trade names)

Mode of action-based labelling

- A simple set of codes to be used on product labels that show at a glance which cross-resistance group (or groups for active ingredient mixtures) a product contains

Resistance Management
ZAMPRO contains amelotradin, a triazolo-pyrimidylamine fungicide from the Qxl (Quinone binding site unknown) MODE OF ACTION group Group 45 Fungicide, and dimethomorph, a cinnamic acid amide fungicide from the Carboxylic Acid Amides (CAA) MODE OF ACTION group Group 40 Fungicide. Resistance to this fungicide could develop from excessive use. To minimise this risk use strictly in accordance with the label instructions and resistance management strategies that

- The codes are based on those used internationally, but are adapted to suit New Zealand conditions

Mode of action-based labelling

- Need to keep MOA charts up to date
- MOA codes, Charts on the NZPPS website and in Novachem manual
- Strategies show MOA codes and recommended resistance risk statements for product labels
- AGCARM fully support
- ACVM require this on all product labels

What is your Role

AGCARM

Fund/contract and share findings of surveys/ monitoring
Collection and sharing of information
Input into the priorities for resistance management
Support and work in the Task Groups
    - Updating strategies in the Task Groups
    - Ensure new strategies are prepared for new MOA
Ensure MOA charts are up to date
Label, technical and promotional material to convey the strategies
Support resistance management

ACVM

Engage with MPI to encourage monitoring
Work with registrants on label requirement
Share information from adverse reports

What is your Role

Science

Advocate for resistance research
Undertake the research
Publish and communicate the findings
Contribute participate to the Task groups

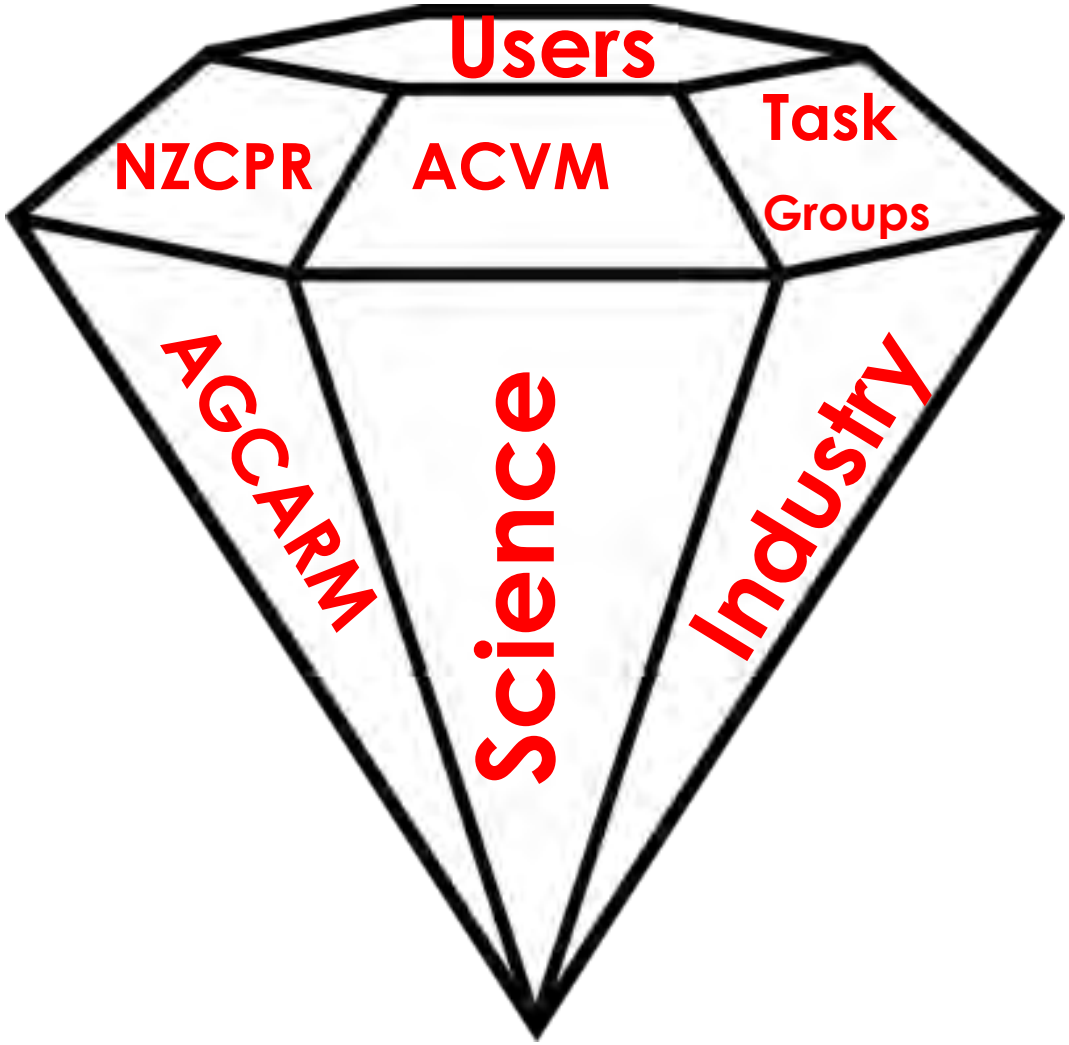
Industry

Support resistance management
Fund/contract and share findings of surveys/ monitoring
Collection and sharing of information
Input into the priorities for resistance management
Support and work in the Task Groups
Use/ Promote and Communicate the strategies

Resistance management

The Strategy- Diamond.

Together it works



Right now, for grape powdery mildew

1) Complete the research

2) From a task group

3) Revise strategies

4) Communication