NSW GOVERNMENT | Department of Primary Industries

Options for vineyard reinvestment: reworking, replanting and top-grafting

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Nick Dry, Foundation Viticulture

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Nick Dry

Foundation Viticulture
0411 487 495
nick@foundationviticulture.com
www.foundationviticulture.com

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Acknowledgements

Cover image: An example of a vine that has been reworked from the trunk. Photo: Nick Dry.

Wine Australia

NEW SOUTH WALES wine

Contents

Introduction

Vineyards in NSW are getting older. There are large areas of vineyards that were planted in the 1990s and early 2000s. While in some circumstances these could be considered relatively young, many have been experienced periods of drought, lower than optimal inputs during downtimes, increased prevalence of trunk disease and spread of grapevine virus, which all contribute to reduced vineyard productivity. Furthermore, given the demand for planting material during the boom of vineyard expansion, the health status of some vines might not have been ideal when planted.

It is not only the vines that are ageing. Vineyard infrastructure, including the posts and wire, end-post assemblies and the irrigation systems are also showing signs of wear and tear. Finally, the soils have received 20 years of compaction, reductions in fertility and organic matter, as well as increased salinity and sodicity, all affecting vine productivity. Consequently, the NSW grape and wine communities are now faced with vineyards that are showing declining yields and quality while requiring increased costs due to the inefficiencies associated with ageing infrastructure and declining soil health. This means decisions need to be made about what to do with these vineyards.

Investing in either reworking, replanting or top-grafting are three frequently discussed options. Deciding on when to invest and which option is best for your vineyard is not easy as there are many factors involved. This guide aims to provide some vineyard and regional level context on what those factors are and some discussion on the main considerations for each of the options. The information in this guide is based on the available literature as well as practical information developed through workshops and ongoing discussions with vineyard managers and viticulturists across NSW.

Vineyard reinvestment options

Different regions have different terms for what is described below, but for this document, we will be using the following terms and definitions.

Reworking

Reworking refers to the process of making changes to the vine structure to correct underperforming vine yield or fruit quality. The practice generally involves removing the top of the trunk and cordon and training a new shoot (Figure 1), but it may also involve only removing and replacing the cordons. Remedial surgery is a term that is sometimes used in viticulture to describe grapevine trunk disease (GTD) related correction resulting from either Eutypa dieback (ED) and/or Botryosphaeria dieback (BD).

The practice of reworking has been around since the beginning of viticulture, but the first widespread use of it in Australia was to train bush vines onto a permanent wire for ease of management and mechanisation.

Increasing trunk disease and cordon decline over the last 10 years has led to increasing knowledge and technical application of reworking. It is now seen as an integral part of the standard annual program for most viticultural enterprises to ensure that their vineyards retain long-term viability.

Figure 1. An example of a vine that has been reworked from the trunk. Photo: Nick Dry.

Replanting with grafted vines

With the risk of phylloxera and the benefits that a well-selected rootstock can bring to your vineyard, it is highly recommended that serious consideration is given to using grafted vines when replanting. These are produced by grafting a single scion bud (taken from a *Vitis vinifera* cutting) onto a rootstock cutting, which is almost exclusively a phylloxera tolerant/resistant variety. The grafting process is generally performed in a controlled environment in a nursery via an omega or v-graft. Grafted vines grown in a field nursery will be supplied as a dormant rootling and grafted vines grown in a greenhouse are referred to as potted vines, green-tops or spring-banded vines. Grafted vines were first used in the late 19th century to combat the threat of phylloxera.

Top-grafting

Top-grafting is the practice of grafting a scion bud (taken from a *Vitis vinifera* cutting) into the trunk of an existing vinifera vine and re-establishing the structure of that vine from the resulting new scion shoot (Figure 2). Top-grafting is almost exclusively used where a grower would like to change variety or clone, however it has also been employed on reworked vines that have not thrown a water shoot. There are three options for top-grafting: a chip-bud, cleft graft or t-graft. The chip-bud is most common because of its higher success rate (Cowham 2008). Top-grafting techniques were first developed to graft scion onto American rootstock

following a phylloxera outbreak. The commercial application of top-grafting mature vines to change varieties became more prevalent in Australia in the late 1970s and early 1980s to help meet the increased demand for white grape varieties (Henschke and Dry 1982). Top-grafting is now widely practiced in almost all regions in Australia.

Figure 2. A close-up of bud-burst following top-grafting. Photo: Nick Dry.

When to reinvest?

Picking the moment to reinvest in your vineyard or block is critical. Every vineyard has a different trigger point at which reinvestment is optimal. Monitoring yields over time is one way to track block performance, but not all vineyards have good record-keeping, so this might not be possible. Calculating the percentage of unviable cordon or percentage of missing metres of cordon per hectare (i.e. what percentage of the vine cordon is producing grapes) is another useful parameter that will help with the decision. This can be calculated through vineyard assessments but there are also drone or satellite-based normalised difference vegetation index (NDVI) mapping services that can provide this information (Bowman 2018).

An important point that was raised by a vineyard manager during the consultation sessions was that attempting to rework following drought is a good example of missing the optimal trigger point. While drought will highlight problem blocks, the vines are likely to struggle to produce sufficient growth to develop the new vine architecture.

Prevention is better than cure!

Advice from experienced viticulturists and vineyard managers suggests that, after about 20 years, reductions in yield and quality as a result of declining wood health become apparent. Therefore, monitoring should begin well before the effects become obvious. This might mean that as blocks reach 15 years, they are reviewed and an initial plan is put in place to begin reworking any problematic vines.

Timelines

Whether you decide to rework, replant or top-graft, planning must begin early. The duration of each option from initial planting to filling the wire varies (Table 1).

Table 1. The duration of each option from initial planning to filling the wire.

Process and detail	Time from initial planting to 'filling the wire'	Total time (months)	Number of lost harvests	Comment
Replanting dormant rootlings, no fallow period, top tie year 1	September year 1 to April year 4	44	3	Pushing vines to fill the wire in the first year will reduce the timeline by 1 year
Reworking from the trunk, fill the wire in year 1	September year 1 to May year 2	21	1–2	Might end up with better vine structure by not cropping in the second year after reworking
Top-grafting, fill the wire in year 1	September year 1 to May year 2	21	1	Assuming all goes well with the top-grafting process

Which reinvestment option is best for your vineyard?

There are many vineyard-specific factors involved including vineyard ownership and the operating environment at the regional level. The complexities involved mean that it is possible and reasonable for two different management teams to develop two different plans for the same vineyard or block. Figure 3 shows some of the factors to be considered when deciding.

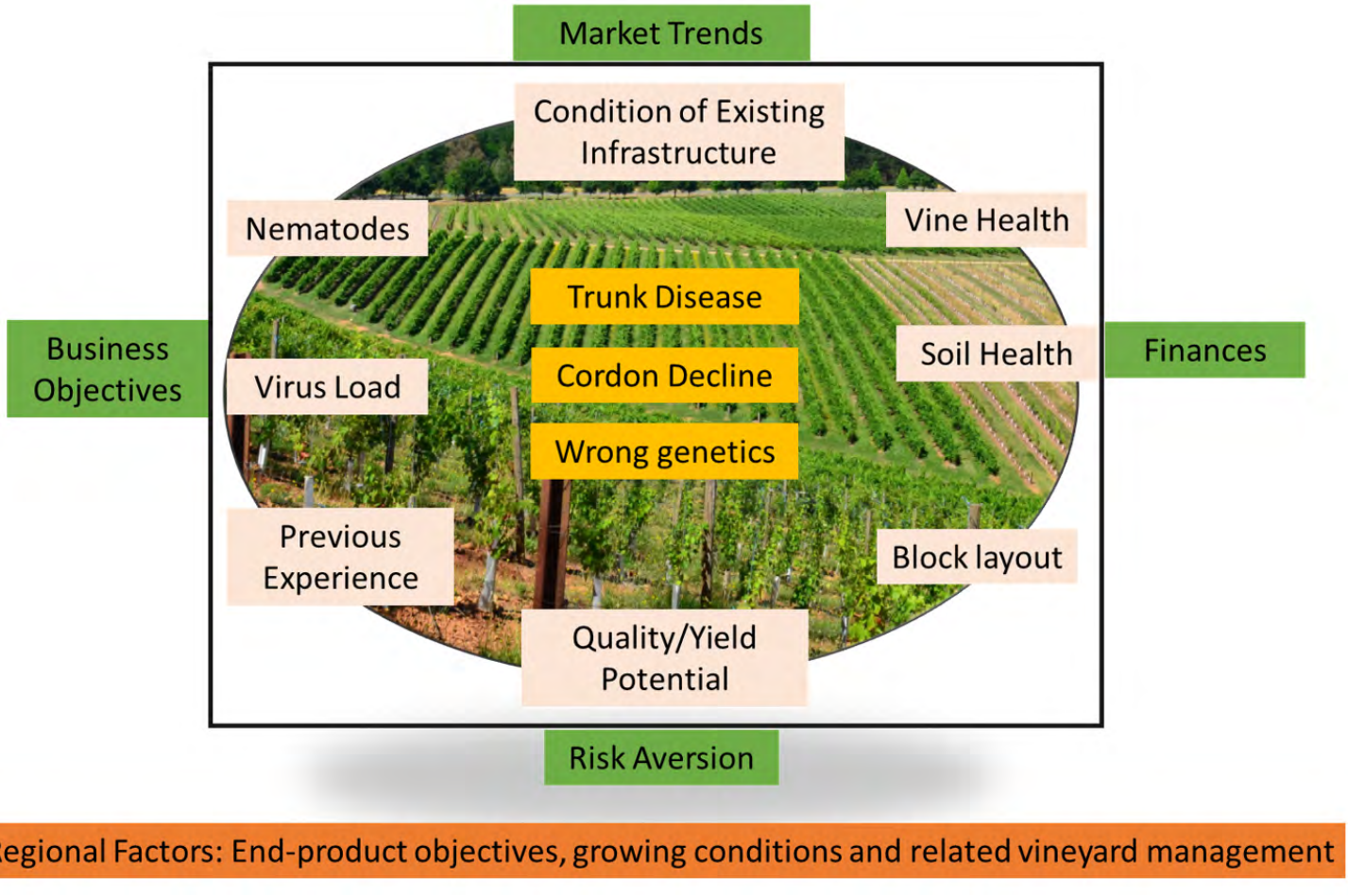

Figure 3. Factors to consider when deciding whether to rework, top-graft or replant. Source: Nick Dry.

Primary reasons

A good starting point is to define the primary reason or underlying problem for reinvesting in the vineyard. Some of the questions to consider include:

- is the problem related to trunk disease?
- do you have non-trunk disease cordon decline?
- what percentage of the vineyard is affected?

Spending significant time in the vineyard assessing the incidence and spread of the problems is required to answer these questions.

Other reasons are related to the variety or rootstock. Do you need to change the variety to something that better suits your portfolio, gets you a better price or is better suited to the climatic conditions, or do you need to consider changing rootstock to better match the site?

If you do not know the underlying reason for reinvesting, then you are essentially making a guess on which option is best suited to your site. Making the wrong decision could have significant financial implications for your business.

Secondary considerations

Secondary considerations are related to the vineyard status and are particularly important when deciding whether to top-graft, rework or replant.

Using real estate investment terminology, analysing these secondary considerations is really about making sure your vineyard has 'good bones' for reinvesting in top-grafting or reworking and that you are 'not throwing good money after bad'.

Key questions to consider include:

- will the infrastructure last beyond the reinvestment pay-back period?
- did the block have good quality and yield potential before problems started?
- does the current block layout suit your plans?
- is there any virus?
- is the soil in good condition?

Vineyard suitability checklists are presented in Table 5 on page 11 for reworking and in Table 9 on page 19 for top-grafting.

Strategic and financial factors

Further influencing factors require more strategic thinking. How are your finances? What is the cash flow situation? How much work can you afford to do? What are the market trends? Is it the right variety to meet your goals? What is your 10-year plan? Finally, how much risk are you willing to take? If you are looking to try a new process like top-grafting or to rework a trunk disease-affected vineyard, understanding risk is important.

Regional and climatic factors

Each region has factors that strongly influence whether it is best to rework, replant or top-graft. These are based on the end-product objectives, growing conditions and related vineyard management. The following information was developed from consultation workshops with NSW vineyard managers and viticulturists.

Warm-hot/low rainfall climate (based on Griffith)

In these regions, the focus is on yield from younger vines (Table 2). The longer growing season, access to water and the quick establishment of newly planted vines

means that replanting is generally the preferred option. An exception is on relatively young vineyards (with good infrastructure and vine health) where you would like to change the variety by top-grafting or those exhibiting problems associated with tight cordon wrapping, as these can be fixed by reworking.

Table 2. Key considerations influencing reinvestment decisions in warm-hot/low rainfall climates.

End-product objectives	Growing conditions	Vineyard management
Profitability is driven by the yield from younger vines	Lower rainfall and therefore lower incidence of trunk disease	Higher reliance on vineyard mechanisation, therefore potentially less well suited to reworking and top-grafting
Dynamic variety shifts to match market demands i.e. the requirement for a consistent replanting program	Longer growing season and access to water leads to quicker establishment of newly planted vines, compared with cooler climates	Using higher vigour rootstocks for drought tolerance allows for young vines to establish more quickly

Warm-hot/high rainfall climate (based on Hunter Valley)

Maintaining older vines for quality and wine style, marketing or preservation of genetics are major factors to consider when deciding to rework in regions such as the Hunter Valley (Table 3). However, it is important to also recognise that even after successful reworking, the block yield potential is lower compared with replanting so you must be sure that the block is financially viable at those lower yields. The economics are more favourable if you are making the wine yourself (i.e. value-adding), otherwise growers looking to rework may need to consider negotiating for a higher price/tonne with their winery before reworking their vines.

Another important consideration relates to the higher risk of trunk disease in this region. There is a greater risk in reworking to firstly remove infected wood, and secondly, to prevent reinfection when creating the large wounds associated with reworking.

Table 3. Key considerations influencing reinvestment decisions in warm-hot/high rainfall climates.

End-product objectives	Growing conditions	Vineyard management
Maintaining vine age is an important consideration for quality and wine style	Higher rainfall increases trunk disease (particularly Botryosphaeria dieback)	Consideration how to manage the vines in premium blocks for yields that will allow for the expression of the anticipated style following reworking or top-grafting
Preserving genetics from older vines is important for the region	Higher rainfall increases the need for weed control	Older vineyards have deteriorating infrastructure

Cool-warm/moderate rainfall climate (based on Canberra, Tumbarumba and Orange)

There is a general focus in these regions (Table 4) on the quality benefits that come with older vine age. This coupled with the slower establishment of younger vines means that reworking is perhaps more easily justified. However, it is important to balance this against the opportunities provided by replanting and changing to 'quality' clones and appropriate rootstocks.

Table 4. Key considerations influencing reinvestment decisions in cool-warm/moderate rainfall climates.

End-product objectives	Growing conditions	Vineyard management
Greater focus on quality, lesser focus on yield	Higher rainfall increases trunk disease (particularly Eutypa dieback)	Cooler climates typically have a higher cost of production
Higher value end-product often based on older vines	Cooler conditions and shorter growing seasons will affect how quickly young vines can establish	Rootstocks appropriate to cooler conditions generally have low vigour

The final decision

There is no magic formula to determine the best option for vineyard reinvestment because every site is different and so is every grower. Whatever option you choose needs to be well-planned, properly budgeted, documented and reviewed for future planning. The worst thing you can do is rush into a decision; if in doubt delay for a year, trial some techniques, collect more data, talk to your network about their experiences and continue planning.

Reworking: key considerations

There are multiple ways to approach reworking, so this section aims to trigger thinking that will help you in the planning process.

Grapevine trunk disease

For a successful reworking project, it is critical to remain vigilant in identifying and managing grapevine trunk disease (GTD). We are fortunate there has been some excellent research and extension undertaken in Australia on this and it is highly recommended that you read *Wine Australia's Best Practice Management Guide for Grapevine Trunk Disease* (Figure 4). This guide provides information on disease identification, vineyard assessment and a 'decision tree' for developing a remedial management plan for vines affected with trunk disease.

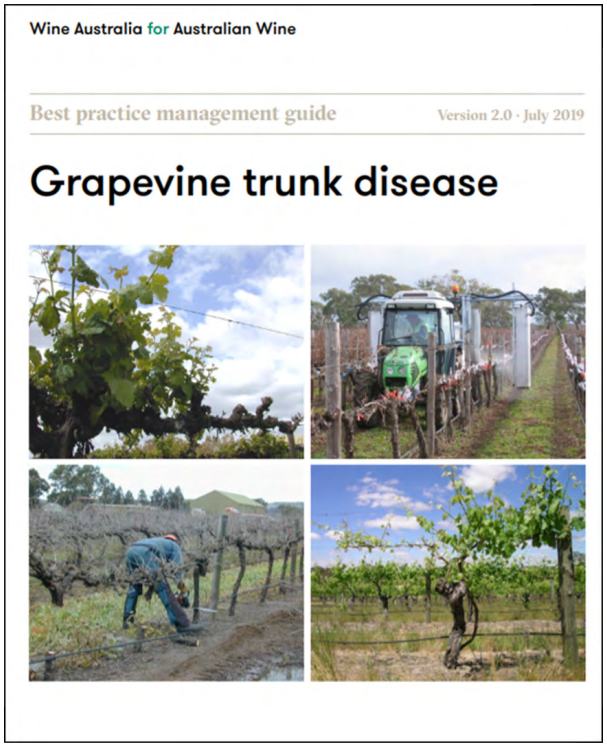

Figure 4. The cover of Wine Australia's best practice management guide for grapevine trunk disease.

Vineyard suitability

Implementing a reworking program to remedy declining wood health is a major undertaking that requires a significant financial commitment. Before starting, you need to be confident the vineyard block you are investing in is suitable. Table 5 is a vineyard suitability checklist for reworking. If you find that you are marking a cross next to some or most of the factors listed, then the best decision might be to remove and replant the vineyard and take it as an opportunity to revitalise the soil, upgrade infrastructure or plant a different variety or clone.

Table 5. A vineyard suitability checklist for reworking.

Vineyard/block attributes	✓ or ×
Trunk disease has not spread to ground level	
Historical performance (yield/quality) was good before problems developed	
Vines are free of grapevine virus	
Variety is suited to reworking	
Block layout/row orientation is suited to current and future requirements	
The vineyard infrastructure is in good condition and worthy of reinvestment	
There is a low proportion of missing vines	
There are no major soil health issues	
The current variety is in demand	
The current variety/clone/rootstock is suited to the site, now and into the future	
No immediate plans to set up for different mechanisation process e.g. Klima or mechanised under-vine weed management	

Varietal suitability

Some varieties are less suited to reworking as they do not produce water shoots as readily as others. Cabernet Sauvignon is the variety most commonly cited in this category. Semillon might also present some challenges, particularly if the vineyard has suffered from prolonged periods of drought before reworking or if the vines are generally in poor health (low capacity to produce new, strong shoots for re-training). There are still options when presented with these scenarios such as:

- training the water-shoots before reworking (Figure 5)*
- top-grafting the original variety into the trunks well below any trunk disease infection
- employing a combination of approaches, beginning with reworking and where vines have not thrown a shoot, use top-grafting to fill in the gaps.

* In this approach, water shoots are identified and trained up to the wire in the season before reworking. The benefit is that it will lead to a quicker return to yield. The key management consideration is in protecting the shoot from damage (particularly from herbicide) during the growing season. As a result, this approach is more successful in regions with lower rainfall and less requirement for weed control. In higher rainfall regions, this approach has been used in combination with grow-guards to protect vines from herbicide damage (see Table 7). There are additional costs associated with training shoots and using grow-guards; this needs to be factored into your decision making.

Figure 5. A water-shoot trained in the season before reworking. Photo: Nick Dry.

Reworking in vineyards with trunk disease (remedial surgery)

Tackling a trunk disease-related problem with reworking is not something that should be done reactively. Before making any decisions, it is highly recommended that you read *Wine Australia's Best Practice Management Guide for Grapevine Trunk Disease*.

One of the key decisions when reworking trunk disease-affected vineyards, is where on the vine to make the cut. Can you get away with only removing cordons or do you need to rework from the trunk? Is this done uniformly across the vineyard or on a vine-by-vine basis? The answer to both these questions will depend on how far the trunk disease has spread within the vine and how far down the trunk it has moved. Generally, trunk disease has a gradual effect and the presence and extent of infection within a vine will not be uniform across the vineyard. If you have experienced operators that can identify symptoms, you can work on a vine-by-vine

basis where cuts are made until symptoms are no longer observed, with the final cut made at least 20 cm below the infected woody parts (Sosnowski et al. 2017). While this will make the process slower, if done properly, this option will reduce the length of shoot required to reach the cordon wire and hasten re-establishment.

If operators are unable to identify symptoms, then a decision to cut all vines at a uniform height from the ground should be made. The closer to the ground the vine is cut, the lower the risk of retaining the disease, but the further you need to train the new shoot.

Reworking in vineyards without trunk disease

Reduced wood productivity in vineyards without trunk disease is generally associated with cordon strangulation (Figure 6) from tight wrapping at the establishment site (Caravia et al. 2015) or where spurs have been lost through mechanical damage from harvesters and pre-pruners.

The key decision will be whether to only rework the cordon, to rework from the trunk, or whether to combine both approaches. Cordon replacement is the preferred option as it tends to produce a quicker turn-around on yield. However, suitability for this option will depend on whether there are any appropriately placed replacement spurs in the crown that will produce shoots to be trained as a cordon. If there are no replacement spurs or the spurs are sitting too high above the cordon wire, then the vines should be cut at the trunk and a new water shoot trained (Table 7).

While vineyard assessments before reworking might not have identified trunk disease, it is important to remain vigilant for symptoms as shoots derived from an infected part of the vine will eventually express trunk disease symptoms.

Figure 6. Loss of spur positions from cordon strangulation. Photo: Nick Dry.

Whole row/block approach vs individual vine approach

Based on *Wine Australia's Best Practice Management Guide for Grapevine Trunk Disease*, deciding on whether to rework large areas (whole rows/complete blocks) or individual vines is determined by the grape value and percentage of vines affected. While this guide was written for trunk disease-affected vineyards, this approach will work in vineyards with cordon strangulation or where spurs have been lost through mechanical damage from harvesters and pre-pruners.

The **whole row/block approach** is better suited to vineyards where grape value is lower and/or where there is a higher percentage of symptoms. The benefit is that it gets the job done uniformly and the prescriptive approach is well-suited to vineyards that are using less experienced operators.

The **individual vine approach** is better suited to higher value grapes or where there is a lower percentage of symptoms across the vineyard. This approach is particularly successful when integrated into an annual management plan but does require a more experienced operator who can make decisions 'on the run'.

Developing the new vine structure

The whole premise of reworking is to develop a new vine structure with healthy, strong wood and well-spaced spurs. On sites with low vigour potential (marginal soils or where soil nutrition is low), increasing nutrient inputs in the period leading up to reworking will help build vine capacity and maximise the opportunities for the vine to produce a strong and healthy shoot that will ultimately become the foundation of the new vine structure.

On sites with high vigour potential, it might be necessary to leave two or more water shoots because if all the vine's energy is directed into one shoot, it will result in long internodes and excessively spaced spur positions.

It is essential to allocate and budget for multiple passes during the first two growing seasons to effectively manage vine training and ensure vine yield is re-established as rapidly as possible. Losing a harvest because you are not keeping up with vine training will very quickly undo the economic benefits of reworking.

Trunk disease management

Even if you are reworking for reasons apart from trunk disease, it is still important to implement trunk disease prevention strategies. Again, *Wine Australia's Best Practice Management Guide for Grapevine Trunk Disease* is your go-to resource on this subject. The guide focuses on the following as key prevention strategies:

Timing – trunk disease spores are released after rain; avoid cutting trunks and cordons in wet weather.

Wound protection – several products can be applied to wounds (Table 6) that are effective against trunk disease spores.

Disposing of the woody parts of the vine – woody parts potentially contain trunk disease spores and need to be either buried or burnt. Mulching is not sufficient to reduce the risk of retaining inoculum (spores) in your vineyard.

Retaining value: post-process management

While the new vine architecture is maturing, it is important to manage the vines appropriately to retain the value of the financial investment.

Vine balance – the primary aim of reworking is to increase yield, but it is important not to over-crop the vine in the first couple of seasons as this can have negative implications on the quality or desired wine style.

Structural support – developing a new trunk and cordon might need additional support such as a catch-wire to prevent canopy roll and excessive fruit exposure.

Harvesting – hand-harvesting or a 'gentler' machine harvest set-up might be required to avoid snapping the newly established trunk and cordon.

Documentation and review – any reworking process should be documented and evaluated for success to help guide any future decisions on reworking.

Table 6. Registered wound treatments to control Eutypa dieback (ED). Recent research has confirmed that these treatments are also effective for Botrysphaeria dieback (BD). Follow label instructions.

Example trade name	Active ingredient	Application method
Acrylic paint	n/a	Paint brush
Greenseal™	Tebuconazole	Bottle top applicator
Garrison Rapid®	Cyproconazole	Bottle top applicator
Emblem®	Fluazinam	Sprayer
Gelseal™	Tebuconazole	Sprayer
Vinevax™ Wound Dressing	Trichoderma atroviride	Paint brush/hand trigger or backpack sprayer

Adapted from *Wine Australia's Best Practice Management Guide for Grapevine Trunk Disease*.

Reworking case studies

Table 7. Case study 1 – reworking from the trunk.

Region	Hunter Valley
Variety	Chardonnay
Reasons for reinvestment	1989 planted vineyard, 29 years old when reworked Trunk disease affecting yields
Chosen process and justification for the decision	• Cut off vines (ultimately found that just above the drip line was the best height (Figure 7) for the vines and operators) • Remove old cordon and wire (Figure 8) • Run, strain and staple new wire • Tie vine trunks to new wire (Figure 9) • Install grow-guards (tubes were specially made to fit over old trunks) - Tubes used for weed control - Increased cost of $550 per hectare + installation
Do you consider the project successful why/why not?	'Very successful when training was done in good time, however any delay with training caused problems with excessive growth inside the tubes. There has definitely been a yield increase from where we were before reworking'
Take-home message	• Investing in a well-planned, additional process (i.e. the grow-guards) can pay off • Reworking benefits from a 'thinking outside the box' attitude

Figure 7. Case study 1, removal of the vine structure (winter year 1). Photo: Brett Keeping.

Figure 8. Case study 1, cordon and spur establishment following reworking (winter year 3). Photo: Brett Keeping.

Figure 9. Case study 1, fully established vine structure following reworking (winter year 4). Photo: Brett Keeping.

Table 8. Case study 2 – reworking from the cordon.

Region	Hunter Valley
Variety	Semillon
Reasons for reinvestment	Only 3–4 functioning spurs per arm, some evidence of trunk disease, but vines generally in good health
Chosen process and justification for the decision	It is difficult to get Semillon to throw a water shoot and the shoots can be brittle; they are also not easily forced down onto a wire Based on those factors and with existing spur antlers sitting well above the cordon wire, it was decided to train new fruiting canes onto the existing foliage wire (Figure 10 and Figure 11) Cane selection to avoid trunk disease where possible
Do you consider the project successful why/why not?	'Too early to tell, but we expect to gain an additional 15 years of productivity and yield increases of around 25%'
Take-home message	• Work with the attributes of the variety • When reworking, be opportunistic in using existing resources and in this case, converting the existing foliage wire into the cordon wire

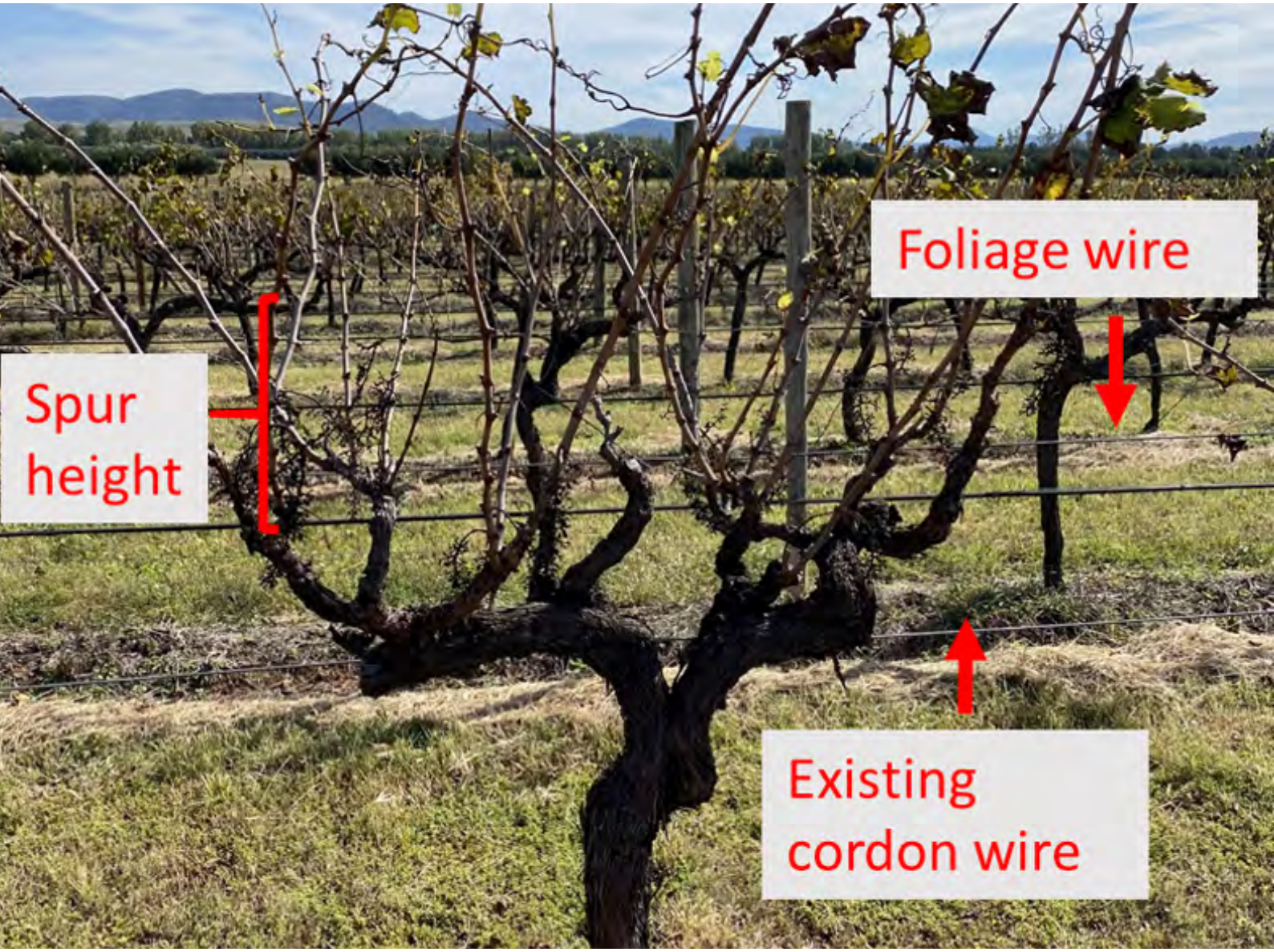

Figure 10. Case study 2, vine structure before reworking. Spur height is sitting well above the existing cordon wire. Photo: Liz Riley.

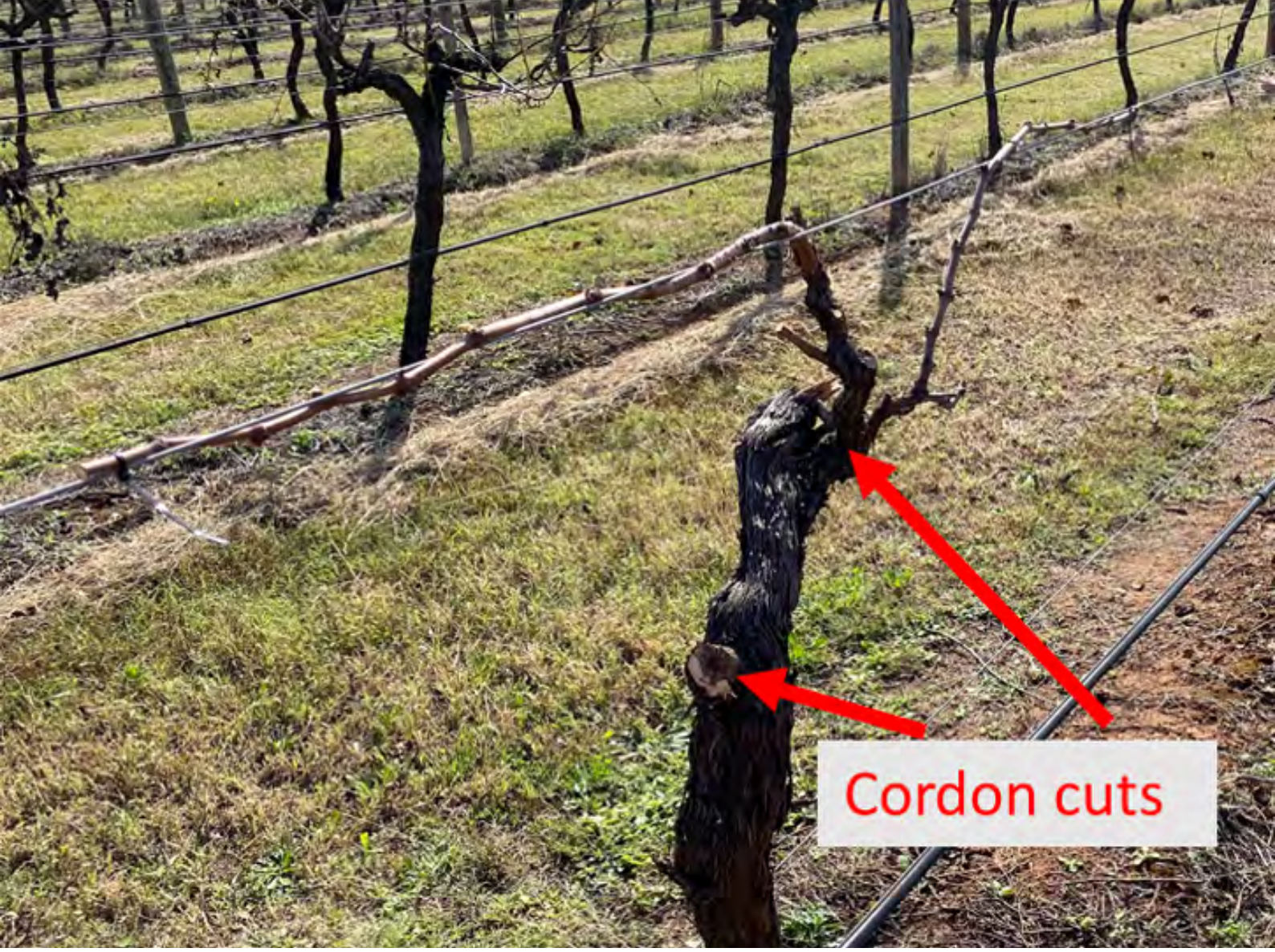

Figure 11. Case study 2, vine structure after reworking. The new fruiting cordon has been trained to the existing foliage wire. Photo: Liz Riley.

Top-grafting: key considerations

Top-grafting is an excellent way to rapidly change a variety or clone without losing multiple harvests, but success is not guaranteed. Vineyard suitability, vine health, commitment to post-process management and a willingness to carry risk are necessary considerations in the top-grafting process.

Vineyard suitability

Top-grafting is a major undertaking that requires a significant financial commitment, so before starting, you need to be highly confident the vineyard block you are investing in is suitable. Table 9 is a vineyard suitability checklist for top-grafting; it has been adapted from Hoare T. 2017. Reworking vineyards – why when and how? Part 2. *Wine and Viticulture Journal*, 3: 51–55.

Cuttings

Grapevine virus is a major consideration. The potential detrimental effects of combining a virus from the scion and rootstock or introducing a virus from a rootstock into a sensitive scion are high; both the scion and rootstock must be tested.

Before ordering or taking cuttings, calculate how many buds are required. The number of useable buds will depend on each cutting, which will be influenced by variety, growing season and the grafter's preferred bud size. The general rule is to budget on two buds per cutting plus some extras for any re-grafts. Cuttings supplied from nurseries and vine improvement groups will generally come in bundles of 100.

For example:

1,500 vines × 2 buds per vine = 3,000 buds

@ 2 buds per cutting = 1,500 cuttings

+ 10% for re-grafts* = 1,650 cuttings; rounded up to 1,700 cuttings.

*Do not give the spare cuttings to the grafter in case they get cut up for the first pass.

Table 9. A vineyard suitability checklist for top-grafting.

Vineyard/block attributes	✓ or ×
Current variety is not viable and unlikely to change in the short-term	
New variety selected based on regional suitability and saleability in the short to mid-term	
Vineyard infrastructure is in good condition and predicted to remain so for the mid-term	
Vine trunk suitability – diameter straightness, disease status acceptable, general health (no post-bushfire or frost damage)	
Vine uniformity high; low numbers of missing vines	
Costs of grafting and cash flow organised	
Vineyard labour for training is accessible and reliable	
Knowledge of grafting preparation, post-grafting management, timing and pitfalls well understood by vineyard manager	
Virus testing performed on a representative sample from the vineyard rootstock to be grafted and diagnostic results confirm suitability to grafting	

Adapted from Hoare T. 2017. Reworking vineyards – why when and how? Part 2. *Wine and Viticulture Journal*, 3: 51–55.

Top-grafters are characteristically particular about budwood, which is understandable as bud matching and quality are critical to grafting success. Always check with the grafter for their preferred cutting diameter specification before acquiring the cuttings. If the cuttings cannot be supplied to these specifications, order extra cuttings to provide more material to work with. Also, check with the grafter for their preferred treatment and storage conditions. Usually, cuttings should be tagged (with a permanent marker), hydrated, stored in clean plastic bags and refrigerated between 2 and 5 °C. Work in 8–10 days' notice for getting the cuttings from the supplier to the grafter, especially if the cuttings are coming from interstate. Avoid transporting cuttings during hot weather!

If the cuttings are coming from a commercial vineyard, inspect the block preharvest to check and tag any off-types (i.e. vines of the wrong variety) and also postharvest (before leaf-fall) to identify and tag any virus-infected vines. Remember, the quality of the cuttings will 'make or break' your vineyard reinvestment; do not diminish the importance of this critical resource.

Commitment to post-grafting management

Training the new shoots is critical to success and the best top-grafting (Figure 12) outcomes result from having quick, but regular training passes (e.g. 7–10). Table 10 (from Hoare 2017) is an excellent resource for planning your post-grafting management program. A good tip is to develop this program before the growing season and then confirm the availability of your workforce for the peak labour periods.

Table 10. Post-grafting management checklist for factors contributing to the success of field grafting. Source: Hoare 2017.

Management	Monitoring symptoms	Action
Soil moisture	Too wet: excess sap flow, delayed budburst, stunted shoots. Perform 'squeeze test' around buds, look for visual dampness on the trunks	Make cuts, withhold irrigation, continue monitoring until budburst; more than one pass of cuts might be needed
Frost	Frost weather warnings	Mow cover crop, mid-row growth, clean out under-vine weeds and debris, roll mid-row if soil is exposed; activate frost fans/irrigation sprays
Pest and disease	Monitor for mechanical damage to buds, leaves and shoots. Observe delayed budburst, stunted or damaged vegetation	Apply appropriate control within industry guidelines to maintain a pest and disease-free vineyard
Secure grafted shoots	Avoid blown out or broken shoots	Install training strings immediately after grafters finish and prepare vine trainers for the first few training passes
Training/ desuckering	Rolling and unsecured grafted canes. Water shoots/suckers on the trunk	Train shoots onto a wire, remove all water shoots except one at the highest point until grafted buds have burst; this can then be removed. Expect up to 10 training passes
Liaise with grafters	Unsure or inexperience with post-grafting management	Call grafters with any questions to discuss post-grafting management
Prepare for regrafts	The first round of grafted buds did not grow	Consult with a grafting contractor. Maintain at least one water shoot at the highest point on each vine to preserve it for grafting the following season

Risk

Even with all the right preparations and a vineyard well-suited to the process, top-grafting can fail due to growing season conditions (too hot/too cold/too wet) or because of unexpected incompatibilities between the scion and rootstock. When top-grafting goes wrong, it can take years to remediate with re-grafting and training; in some cases, only complete removal and replanting can fix the situation. Growers must be aware of these risks before committing to the process.

"We trusted that the source was good. Two years after getting an excellent grafting success rate and all the money invested in training, we found that we had white varieties in our patch of Shiraz. It was devastating".

Figure 12. An example of a well-managed vine, 5 months after top-grafting. Photo: Nick Dry.

Replanting: key considerations

Replanting is the preferred option where vineyards:

- are suffering from high levels of trunk disease
- cannot support strong shoots developing for re-building the vine architecture
- have inappropriate infrastructure or block layout
- have unsuitable existing variety, clone or rootstock.

Vine replacement or total vineyard replacement

Removing and replacing only the vines (and possibly the cordon wire) will cost about half the amount of a complete vineyard redevelopment. However, completely redeveloping the vineyard is an opportunity to start again and learn from mistakes or build on successes. These could be related to row orientation, block layout or infrastructure materials and design. Completely redeveloping the vineyard also provides an opportunity to remediate the soil without infrastructure being in the way. Regardless of the option chosen, be aware of virus transmission from remnant roots, especially grapevine leaf-roll viruses.

Leaf-roll 3 virus transmission from remnant roots

Leaf-roll 3 (LR3) virus is the most economically significant virus in Australian viticulture, affecting both yield and quality. There have been reports of LR3 virus being transmitted from recently removed vines to new plantings, leading to high levels of infection in the newly planted vines (Daane et al. 2012).

A mealybug species that spends part of its life cycle on grapevine roots is the main cause. When vines are removed, remnant roots that are left in the ground remain as a viable food source for the mealybug. If the old vines are infected with LR3, it will also be in the roots. When feeding on these roots, the mealybugs spread the virus to the roots of the newly planted vines. Therefore, removing these remnant roots is critical and should be the primary focus of managing this potential problem. The current recommendation is to remove roots down to at least 30 cm (Bell 2020). Note: applying herbicide to vines before removal did not affect the viability of remnant roots and so is not recommended as a control measure (Bell et al. 2009).

Grafted or own-rooted vines

The difference between own-rooted vines and grafted vines is that the root portion of grafted vines has a hybrid American vine species whereas own-rooted vines are ungrafted and are therefore growing on their 'own roots'. Own-rooted vines are susceptible to phylloxera whereas grafted vines can grow in the presence of this soil-borne pest. Depending on the rootstock, other potential benefits of using grafted vines include tolerance to salinity, drought and nematodes, influencing vine vigour, yield or rate of ripening.

The main consideration when selecting between grafted or own-rooted vines is cost; a grafted vine costs approximately 2.5 times more than an own-rooted vine. However, this could be considered a small price to pay for insurance against phylloxera. Furthermore, there is scientific and commercial evidence suggesting that appropriately selected rootstocks will increase grower profitability compared with

own-rooted vines by either leading to more consistent yields (without affecting quality) or by reducing inputs (water and nutrients). These increased profits will more than pay for the increased costs of the planting material over the life of the vineyard (Dry 2004).

Dormant rootlings or potted vines

Dormant rootlings should always be the first-choice product because they are propagated and callused in the nursery, then grown in a field nursery (Figure 13). This means they are already one year old and fully lignified with high carbohydrate levels when supplied. The only negative is the long lead time (15–18 months) from order to supply, whereas potted vines (green vine/spring banded vine), which are rapidly grown in a greenhouse, are supplied after about 10–12 weeks. This means potted vines (Figure 14) will only be partially lignified and have limited carbohydrate stores when supplied. They are also supplied later in the season when it is potentially hotter and drier.

Figure 13. Dormant rootlings are grown in a field nursery from late spring until late autumn. Photo: Yalumba Nursery.

Figure 14. Potted vines are grown in a greenhouse for approximately 10 weeks and are supplied in late spring/early Summer. Photo: Yalumba Nursery.

Rootstock selection

Depending on experience, choosing a rootstock for a vineyard can be complicated. However, many resources are available to help. Most notably is the Wine Australia funded web-based 'Rootstock Selector' (www.grapevinerootstock.com).

This highly recommended tool was adapted from the Yalumba Nursery Rootstock Selector and has been updated using the latest research findings from Australian and international resources; hence it should be the starting point to any investigations on rootstock selection. The tool is easy to use and allows growers to input their general site information and, based on these data, a list of suitable rootstocks and detailed information about their attributes will be provided. Importantly, this tool contains updated information on the relative susceptibility, tolerance and resistance of each of the rootstocks to the Australian phylloxera genotypes.

Creating a balanced vine by matching rootstock vigour to scion and site potential

Rootstocks influence vine vigour, so when selecting a rootstock, the inherent vigour of the scion and the site vigour potential have to be considered. For example, a high vigour scion (Shiraz) grafted onto a high vigour rootstock (Ramsey) planted on a high vigour site will produce excessive vigour. Conversely, a lower vigour scion (Semillon) on a low vigour rootstock (101-4) on a low vigour potential site

will produce inadequate vigour to support the crop load. In both cases, maximum quality/yield potential will be hard to meet without significant inputs.

Rootstock characteristics: practical considerations

When selecting a rootstock it is important to recognise that there is no perfect rootstock for a site and that successful rootstock use is as much about understanding and managing the characteristics of that rootstock as the selection itself. In addition to the information provided in the grapevine rootstock selector, here is a list of the main rootstocks used in Australia and the practical considerations of using these.

Ramsey (*Vitis champinii*)

Ramsey rootstock imparts high vigour and generally encourages higher yields. It also has excellent salinity and nematode tolerance. Since it produces a deep and extensive root system, it is the most drought-tolerant of all the rootstocks available in Australia, making it an ideal rootstock for hot regions. To maximise water use efficiency and quality, Ramsey should be irrigated less frequently compared with other rootstocks and vines on their own roots. Growers who manage Ramsey with the same irrigation schedule as other rootstocks or own roots will find that the vines produce excessive vigour.

140 Ruggeri (*Vitis berlandieri* × *Vitis rupestris*)

140 Ruggeri is a moderate to high vigour rootstock with excellent drought and salinity tolerance, making it suited to warm and hot climates. This rootstock produces a large, dense root system, requiring less irrigation than vines on their own roots or any with *V. riparia* in their parentage.

140 Ruggeri is susceptible to producing excessive swelling at the graft union that can result in strangulation and death of young vines within 3–18 months of planting. Typically, the percentage of affected vines is very low but can be higher when grafted to some scion varieties including Grenache and Tempranillo. This rootstock can also be difficult to grow in a field nursery, which can lead to shortfalls with orders. However, once established, this rootstock can produce quality outcomes.

1103 Paulsen (*Vitis berlandieri* × *Vitis rupestris*)

A moderate to high vigour rootstock with excellent drought and salt tolerance and good affinity with almost all varieties. It has produced quality outcomes in warm and hot climates in a range of soil types. It has also performed well on low-moderate vigour potential sites in cooler regions where water availability has been limited. There have been isolated incidences of poor performance of 1103 Paulsen in soils with high or aggressive populations of root-knot nematode (Walker and Cox 2011).

110 Richter (*Vitis berlandieri* × *Vitis rupestris*)

110 Richter is a moderate vigour rootstock with good salt and drought tolerance. It is particularly well suited to moderate to high potential sites in warm climates or low-moderate potential sites in cooler climates. The popularity of this rootstock is increasing as growers and vineyard managers become more familiar with its characteristics. It performs similarly to vines on their own roots with the benefits of having better drought tolerance. It can be a difficult rootstock to grow in the nursery, which can lead to shortfalls with orders. As with 140 Ruggeri, this rootstock is also susceptible to producing excessively swollen graft unions.

5C Teleki (*Vitis berlandieri* × *Vitis riparia*)

This rootstock imparts moderate vigour and is best suited to cooler sites on well-drained clay/loam soils. *V. berlandieri* × *V. riparia* rootstocks (5C Teleki and

5BB Kober) tend to produce more lateral spreading root systems rather than the plunging root systems of the *V. berlandieri* × *V. rupestris rootstocks*. It is important to consider this when designing irrigation systems, i.e. closer spacing of emitters with lower emitter output will better match the lateral spreading root systems. Avoid using this rootstock on sandy soils in warm climates and at sites with saline irrigation.

5BB Kober (*Vitis berlandieri* × *Vitis riparia*)

5BB Kober imparts moderate to high vigour and productivity and has similar characteristics to 5C Teleki. It is best suited to cooler sites on well-drained clay/loam soils.

101-14 (*Vitis rupestris* × *Vitis riparia*)

This rootstock has low vigour and a short vegetative cycle, which makes it well suited to cool climate regions. This rootstock produces a shallow, lateral spreading fibrous root system and has higher water requirements compared to other rootstocks. Planting this rootstock should be conditional on consistent access to irrigation water or in regions with high summer rainfall. Even in cool climate regions, if planted on exposed, shallow or rocky sites, it might struggle to maintain canopy freshness in the summer heat.

3309C (*Vitis rupestris* × *Vitis riparia*)

This rootstock has not been widely planted in Australia but is one of the most widely planted rootstocks in premium wine-growing regions in North America, Europe and New Zealand. The rootstock is low vigour and, while it is reported to have better performance in dry conditions compared with 101-14, it will still need consistent access to good quality irrigation water in most regions.

Schwarzmann (*Vitis rupestris* × *Vitis riparia*)

This rootstock imparts moderate to low vigour and good productivity. Like the other *V. rupestris* × *V. riparia* rootstocks, it is not drought tolerant and is best suited to deeper soils where there is access to good quality irrigation. Schwarzmann has been reported to take up higher levels of potassium, which can reduce wine quality. It was once a very popular rootstock, but its use has decreased in favour of 101-14 and 3309C.

CSIRO Rootstocks

In the mid-2000s, CSIRO released three rootstocks bred specifically for Australian conditions. These rootstocks have not been widely planted yet so observations on performance are limited. Observations from commercial plantings and trials suggest that M5489 and M5512 have good potential to produce quality outcomes, but further evaluation would be required to determine suitability to specific sites.

Merbein 5489 (*Vitis berlandieri* × *Vitis cinerea*)

Merbein 5489 has been the most widely distributed of the three Merbein rootstocks. M5489 is more vigorous and produces higher yields than M5512 and M6262. Compared with more common rootstocks such as 140 Ruggeri and 1103 Paulsen, vigour is generally lower with similar or slightly lower yields (Dry and McLoughlin 2020). There have been reports of variable grafting success in the nursery, which can limit supply.

Merbein 5512 (*Vitis berlandieri* × *Vitis cinerea*)

This rootstock accounts for approximately 20% of the supply of the three Merbein rootstocks. In terms of vigour and yield, it sits in between M5489 and M6262 (Dry and McLoughlin 2020). When compared with own roots, M5512 is more vigorous

and produces higher yields. There have been reports of variable grafting success in the nursery, which has limited supply.

Merbein 6262 (*Vitis berlandieri* × *Vitis cinerea*)

Merbein 6262 has been the least widely distributed of the three rootstocks. It produces the lowest vigour and yield and would appear to have higher irrigation requirements and higher salt uptake compared to the other two rootstocks.

Maximising quality assurance of planting material

It is important to recognise that bringing any planting material onto your vineyard is a significant threat to your vineyard biosecurity. If the plant material comes with a pest, disease or virus, then it is probably there for the life of the block and could spread into the rest of the vineyard. The quality assurance of planting material can be maximised by ensuring your supplying nursery is accredited and has followed virus and trunk disease management protocols.

Nursery accreditation

Accreditation might be from either VINA (Vine Industry Nursery Association), NIASA (Nursery Industry Accreditation Scheme) or ISO:9001 Quality Management System. Accreditation does not guarantee freedom from pest, disease or virus, but does indicate that the nursery is run with professionalism, has quality systems in place, has product traceability and understands the principles of propagation.

Grapevine virus

To minimise risk the risk of viruses in your planting material, ensure the nursery has:

1. source block inspections in autumn to identify potential vines with a leaf-roll virus
2. virus testing of scion source blocks (using at least 1 in 200 vines in the last 3 years) showing no leaf-roll 1, leaf-roll 3 or grapevine virus A (GVA)
3. recent (in the last 3 years) 'complete' virus testing (at least 1 in 200 vines) of rootstock source blocks showing an absence of:
    - leaf-roll virus 1, 2, 3, 4/4, 4/6 and 4/9
    - grapevine virus A and B
    - grapevine fleck
    - grapevine red blotch
    - grapevine Pinot Gris virus
4. evidence of at least one 'complete' virus test (see list above) on the scion source block.

For further information on virus sampling and testing, see www.awri.com.au/wp-content/uploads/2018/05/Virus-Testing.pdf

Grapevine trunk disease

Infections in planting material can lead to poor vine performance, inability to deal with environmental stress, vine decline and sometimes vine death. The following are the minimum standards to follow to help reduce the opportunities for trunk disease to enter and infect plant material:

- hot water treatment (HWT) is critical for controlling trunk disease but should only be undertaken by an experienced operator who understands the process. Scions and rootstocks should be treated for 30 minutes at 50 °C and rootlings should be treated for 5 minutes at 54 °C

- good nursery hygiene: does the nursery look clean, is there any dust or debris, are benches wiped down regularly, are grafting machines being cleaned regularly?
- pathogens can build up in nursery soils so field nursery rotation should occur after 3 years or soils should be fumigated
- always inspect plant material before planting; the nursery should do this and, to add another layer of quality assurance, there is no reason why you cannot do this yourself. The 'Fit-Vine' app (available from App stores) is a useful tool developed by the National Wine and Grape Industry Centre that will assist you in assessing planting material before planting.

Planting

If you are not planting the vines yourself, it is essential to provide clear specifications on the process you want to be followed. The specifications can be as simple as:

1. create a wedge in the soil using a shovel with approximately a 100 mm opening
2. place the vine in the wedge opening
3. ensure the roots are oriented downwards (to avoid j-rooting)
4. plant the vines so that at least 100 mm of soil is above the root ball
5. firmly push the soil down around the vine to remove air and to ensure maximum contact between soil with roots (i.e. no air holes)
6. gently tug the vine upwards to ensure roots are oriented downwards
7. push back any soil disturbed during tugging.

Planting young vines is the foundation of a 20+ year investment…
take your time and get it right!

Cordon wrapping

Wrapping the cordons at the establishment sites too tightly can eventually reduce the effective cordon length by constricting nutrient flow (Bowman 2018). Below are three options to prevent this from occurring:

1. **Wrap and unwrap**: tightly wrapping shoots helps to provide stability to the vine, but it is important to plan and budget for unwrapping once the trunk has developed sufficiently to support the vine. At this point, cordons can either be wrapped loosely to the wire or fastened with a clip or tie*.
2. **Securing cordons at the establishment site**: fastening clips or ties* can be attached to secure cordons at the establishment site. Research suggests that three ties along each cordon are required, along with some additional support from foliage wires to prevent canopy roll (Caravia et al. 2015).
3. **Cane-pruning**: wrapping and renewing canes each year for the first 4-5 years until the trunk has established sufficiently to support itself is another option that has been used successfully. As with the option of securing cordons at the establishment site, there may be a requirement for foliage wires to prevent canopy roll.

*When using clips or ties it is important they do not end up constricting the developing cordon.

J-rooting

J-rooting is a commonly observed problem in vineyards that occurs when vines are pushed into the ground with the roots getting folded upwards (Figure 15). J-rooting occurs when planting is rushed or where they are not planted properly. J-rooting can lead to root death (Figure 16) and has been associated with the incidence of root and trunk disease (Úrbez-Torres et al. 2014). Vines with J-rooting must expend energy re-orientating the roots downwards. This can severely delay the time to establish and possibly cause long-term problems for the vine.

Figure 15. An example of severe J-rooting. This rootling was removed (dead) 6 months after planting. J-rooting was not the sole reason for vine death but was a strong contributing factor. Photo: Nick Dry.

Figure 16. J-rooting is evident in this vine that was removed 22 years after planting. The block had always performed below expectation. Photo: Nick Dry.

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Options for vineyard reinvestment: reworking, replanting and top-grafting

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www.dpi.nsw.gov.au