EcoVineyards
GROWING RESILIENCE NATURALLY

BEST PRACTICE MANAGEMENT GUIDE

ON GROUND COVERS IN AUSTRALIAN VINEYARDS

by Dr Mary Retallack, Stuart Pettigrew, Jade Killoran, and Dr Ian Chivers

Wine Australia
retallack viticulture
AgDynamics
Healthy Farming Systems

ACKNOWLEDGEMENTS

The EcoVineyards series of best practice management guides (BPMGs) and support materials were developed by a team of subject specialists led by Dr Mary Retallack, Retallack Viticulture Pty Ltd for the National EcoVineyards Program.

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Cover photographs (clockwise from top left): Alyssum planted in the under-vine area in Orange, New South Wales; legumes growing in Margaret River, Western Australia; a mature stand of *Rytidosperma* spp., wallaby grass, Clare Valley, South Australia; [Photos: Mary Retallack], native everlasting daisies planted at Beulah Wines, Boyup Brook, Blackwood Valley, Western Australia [Photo: Craig Nield]; EcoGrower Ben Castine and the Morella native seed nursery, Clare Valley, South Australia [Photo: Mary Retallack]; and under-vine and mid-row cover crop in Yarra Valley, Victoria [Photo: Steve Faulkner].

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For more information about the National EcoVineyards Program please visit www.ecovineyards.com.au @EcoVineyards

ACKNOWLEDGEMENT OF COUNTRY

EcoVineyards proudly acknowledges the Aboriginal and Torres Strait Islander Peoples, and their ongoing cultural and spiritual connection to this ancient land on which we work and live.

As the Traditional Custodians of this land, we recognise their wealth of ecological knowledge and the importance of caring for Country.

We pay our respects to elders past and present and extend this respect to all Aboriginal and Torres Strait Islander Peoples.

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ACRONYMS

AMF arbuscular mycorrhizal fungi

BEF biodiversity-ecosystem functioning

C:N carbon-to-nitrogen ratio

ESG environmental, social and governance

IPM integrated pest management

LBAM light brown apple moth

OM organic matter

RKN root-knot nematode

RLEM red legged earth mite

SOC soil organic carbon

GROUND COVER DEFINITIONS

Term	Definition
Annual regenerating sward	Annual regenerating sward consists of plant species which set seed in spring prior to senescence and regenerate from this seed in the following autumn. Examples include annual medics and sub-clovers.
Awn	An awn is a hair- or bristle-like appendage on a seed head.
Biomass	Biomass is the total sward availability at any given time measured in kg/ha. it is described as either fresh weight (for un-dried green matter, weighed at time of sampling), or dry weight (oven dried weight of the same sample).
C_3 and C_4 carbon pathways	C_3 plants use the C_3 pathway, or Calvin cycle, and C_4 plants use the C_4 pathway, or Hatch-Slack Pathway for the dark reaction of photosynthesis. C_3, which comprises 95% of plants, are adapted to cool season establishment. Conversley, C_4 plants are more adapted to warm or hot seasonal conditions under moist or dry environments.
Chaffy seed	The term 'chaffy' refers to the large amount of loose or attached awns and other seed structures that are not the actual seed required for reproduction, such as adherent lemmas (the outer bracts at the base of a grass spikelet) and paleas (the inner of two bracts surrounding each floret in a grass spikelet).
Cover crop	Refers to any plant population which has been established traditionally in the mid-row of a vineyard, irrespective of species and management.
Ecosystem services	Ecological communities capture biological essential resources, produce biomass, decompose, and recycle biologically essential nutrients, and are known as ecosystem services. These are some of the benefits provided to humans through the transformation of resources into a flow of essential goods and services in an ecosystem.

Term	Definition
Endemic versus volunteer species	The terms endemic and volunteer species refer to similar, but not necessarily the same ground covers. • Volunteer species are those that grow without seeding or planting and can include weedy species, which may or may not be difficult to manage. • Endemic species more often refers to native species, or locally adapted species that naturally occur in the region. They are often a suitable choice for the ground cover program being implemented.
Forb	A forb is a herbaceous flowering plant that is not a graminoid (grass, sedge, or rush). The term is used especially in relation to grasslands and understory.
Functional biodiversity	Functional biodiversity refers to the diversity of functional traits that influence agroecosystem function. For example, some traits of potential importance to agriculture are the capacity of predatory arthropods to provide biocontrol of insect pests like LBAM, grapevine scale and mealybugs, or the capacity of legumes to form symbiotic relationships with rhizobia bacteria, which in turn fix atmospheric nitrogen into plant-available forms.
Glomalin	Glomalin is produced by arbuscular mycorrhizal fungi (AMF). It is a glue-like substance that can adhere to soil micro-aggregates, binding them together to form stable micro and macro-aggregates. Soil aggregation contributes not only to soil structure but also to the protection of organic matter from microbial degradation.
Green manure	Green manure refers to an annual cover crop, re-sown each autumn and grown for maximum spring biomass production. This bulk matter can be mown, and/or incorporated at an appropriate time, usually prior to budburst in late winter or early spring.
Ground covers	Ground cover plants come in many forms, including annual or perennial commercial multispecies cover crop blends as well as naturally adapted native species of grasses that grow in spring (C_3) or summer (C_4), forbs, wildflowers, prostrate growing woody plants and low-growing shrubs and creepers.
Infiltration	Infiltration (or percolation) is the process by which water moves downward through the soil under gravitational forces. The rate of infiltration depends on the water content and the hydraulic conductivity of the soil.
Liquid carbon pathway	The soluble or liquid carbon pathway is a symbiotic relationship between mycorrhizal fungi and 90% of all plants. Plants will purposely produce extra carbohydrates (simple plant sugars) then exude that surplus into soil to feed fungi. Arbuscular mycorrhizal fungi (AMF), in turn, use the exudates to create their own sticky carbon exudate called glomalin. Glomalin is critical in the formation of soil aggregates, which are essential in the creation of soil structure with pores for air and water storage.
Mesoclimate	The climate of a particular vineyard site and is generally restricted to a space of tens or hundreds of metres.
Perennial sward	A perennial sward consists of perennial species such as perennial ryegrass, fescue, cocksfoot, lucerne, white clover, strawberry clover, and most native grasses. Swards of these species persist over summer and can provide year-round ground cover and active root growth.
Seeding rate	Seeding rate refers to the weight of seed distributed over a sown hectare. Within a vineyard, the area sown to a ground cover in the mid-row is approximately 75% the total vineyard area. For example, 7.5 kg of seed would be required to sow a native grass ground cover in 1 ha of vineyard at an effective seeding rate of 10 kg/ha (the seeding rate is species dependent).
Sward	Most commonly refers to grasses but can also relate to a mixture of grass, legumes and other species which are close-growing and form a dense stand that covers the ground. Swards can be annual or perennial, volunteer, or sown species.
Tiller	Lateral stems produced by a grass.

EXECUTIVE SUMMARY

The 'eco' in EcoVineyards stands for 'ecological' vineyard production and regardless of the management system currently employed, we work closely with wine growers across Australia to provide complementary practices with an ecological focus, so we can collectively grow in harmony with nature.

Moving towards more ecologically focused and regenerative production systems is at the heart of the National EcoVineyards Program, and the development of best practice management guides is a key part of this initiative.

This EcoVineyards best practice management guide (BPMG) is part of a series on the following topics:

- soil health in Australian vineyards,
  - Part A (chemical and physical)
  - Part B (biology)
- ground covers (including cover crops) in Australian vineyards – **this guide**, and
- functional biodiversity in Australian vineyards

A summary of each BPMG is included in the table below. These insights are relevant for all wine growing regions in Australia and a broad range of production systems.

Table 1. Summary of the EcoVineyards BPMG series

Soil health	Ground covers	Functional biodiversity
Soil health underpins plant health and vice versa. Soil biology is a key component of pathogen suppressive soils, nutrient cycling, soil structure, carbon storage, and much more. Unfortunately, the living components of soil have often been overlooked when considering soil health. The BPMG on soil health details the tools and resources available to improve soil health in vineyards, with a particular focus on the chemical and physical components in Part A and soil biology in Part B. The BPMG takes growers through the benefits of improving soil health, how to get started, how to assess soil health indicators, setting a benchmark, and monitoring progress over time.	Ground cover plants provide many ecosystem services that ultimately benefit vineyard management and wine grape production. Ground covers include sown ground covers (such as multi-species cover crops), and/or the use of endemic or native species across the entire vineyard floor, including the mid-row and under-vine (natural recruitment, sown and/or planted). The BPMG on ground covers details the tools and resources available to improve ground cover management in vineyards. The BPMG takes growers through the benefits of improving ground cover management, how to get started and how to monitor the outcomes of the changes being made.	Functional biodiversity includes all the fauna (animals) found in association with soils and plants (flora) and the interactions between them, for example, predatory arthropods, microbats, insectivorous, and raptor bird species along with all other life found in association. These species provide a range of ecosystem services, including biocontrol of grapevine insect pests. Biodiversity is the variety of plant and animal life. Each species has a niche in the ecosystem and contributes towards its functionality. The resilience of a system describes its capacity to reorganise after local disturbance (including extreme weather events). The BPMG on functional biodiversity details the tools and resources available to improve functional biodiversity in vineyards and how to monitor progress.

An electronic version of this document is available via https://ecovineyards.com.au/bpmg/

WHAT IS A BPMG?

The EcoVineyards best practice management guides (BPMG) are written by a team of experienced research and extension viticulture, agroecology, and ground cover subject specialists.

Each guide is designed as a 'living document' that can be updated as new information becomes available. It provides a summary of both peer-reviewed scientific information and practical insights for wine growers on each topic covered by the National EcoVineyards Program as well as support materials.

The National EcoVineyards Program aims to accelerate adoption and practice change outcomes specified in Wine Australia's Strategic plan 2020 to 2025, specifically:

- to increase the land area dedicated to enhancing functional biodiversity by 10 per cent
- to increase the use of vineyard cover crops and soil remediation practices by 10 per cent.

An ecological approach

The National EcoVineyards Program focuses on the living components of production systems as an underpinning pillar along with soil health, ground covers, functional biodiversity, and the interactions between each.

These ecological and biologically focused principles are complementary to existing practices, help break the cycle of intervention (saving time and resources), and can assist wine growers with their environmental stewardship reporting requirements.

There are many ways to describe wine growing practices with terms like conventional, organic, low input, regenerative and sustainable often used. We prefer not to use the word sustainable, as to 'sustain' in our view is a low bar and cannot be maintained - either we are moving forward or backward.

In some cases, maintaining the status 'quo is' is actually moving backwards, given the dynamic nature of knowledge being unearthed in this field and the huge potential to solve some of the urgent challenges currently being faced by growers. We cannot continue to do more of the same and expect a different outcome.

We advocate for making small changes with an ecological and regenerative focus and then scaling up as a grower observes benefits and gains confidence in practices that are suited to a particular location.

We are conscious of the urgent and dynamic need to future proof production and grow resilience in our viticultural landscapes, while focusing on fruit quality, financial security, and environmental stewardship. To do this, we need to regenerate and move our thinking and production practices forward in harmony with nature.

Embracing connection

We embrace the knowledge, wisdom and deep connection to land of First Nations Peoples who have been managing Country and living harmoniously on Australia's lands and waters for more than 65,000 years. Aboriginal Peoples are the original custodians of Country and have a deep connection with and intricate knowledge of not only the land and waters but hold knowledge about biodiversity from long-term observations and management, generational presence, and oral history shared through storylines.

Their wisdom and perspectives provide a meaningful contribution to growing a deeper connection with Country and us. We recognise and acknowledge their respect for Country in our approach of continual learning and appreciation of nature in all its diversity.

Grower knowledge gaps

During events held as part of the National EcoVineyards Program, wine growers were asked to identify knowledge gaps they felt were limiting their ability to implement ground cover practices.

The topics ranged from the choice of ground covers, including annual versus perennial species, commercial and native species, how to incorporate all the functional groups of different species, whether to plant mid-row areas or under-vine as well. Selecting species to suit vineyard age and vigour and the specific challenges of establishing native crops were also raised.

Questions of establishment, management, and how to monitor the results, the impacts on soils and water and on grape yield and quality were also highlighted. Ultimately, these all lead to the benefits that can be achieved and the associated insights of cost and benefit.

This BPMG addresses these questions and provides growers with a 'how-to' guide to progress the ground cover journey in their vineyards.

Ecological restoration and functional biodiversity measures that can be employed to help 'future proof' the production of vineyards in Australia against the effects of climate change and extreme weather events are also explored in the EcoVineyards BPMG series.

Join us in exploring this topic with practical insights from a range of subject specialists.

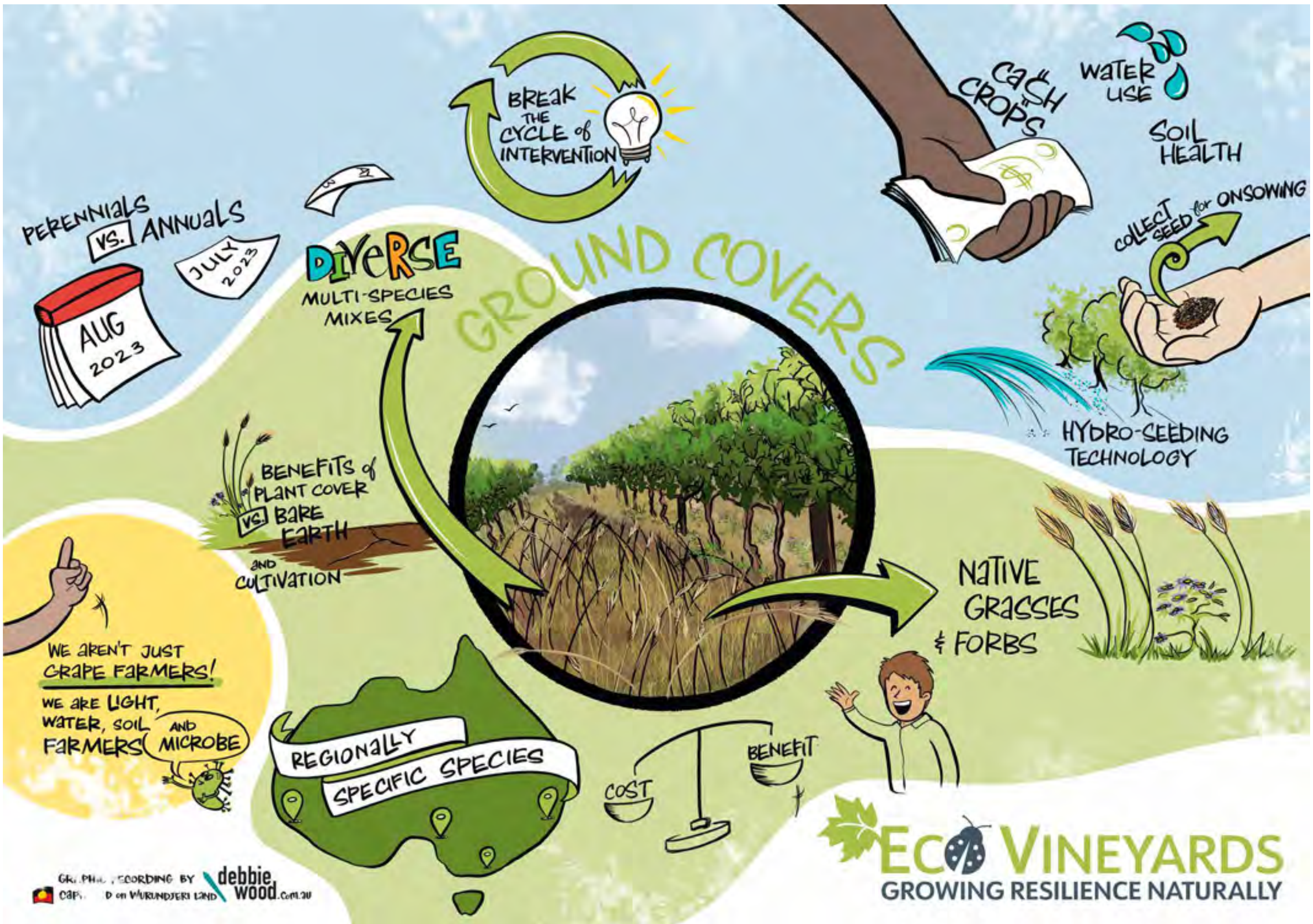
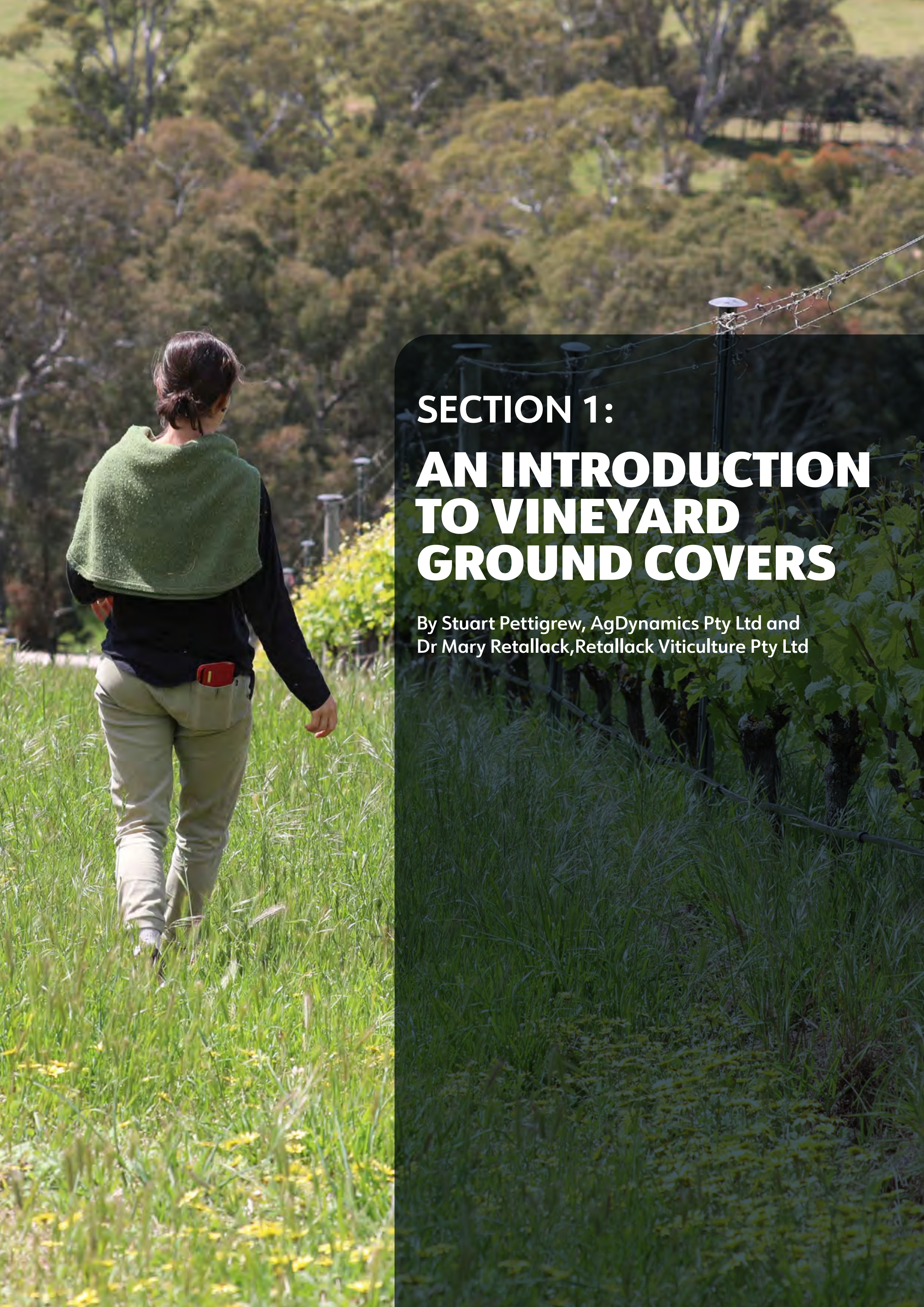


Figure 1. Some of the themes captured within this BPMG on ground covers and more broadly in the National EcoVineyards Program [Image: Debbie Wood]



SECTION 1:

AN INTRODUCTION TO VINEYARD GROUND COVERS

By Stuart Pettigrew, AgDynamics Pty Ltd and
Dr Mary Retallack,Retallack Viticulture Pty Ltd

START YOUR PLANNING HERE

This best practice management guide (BPMG) on ground covers in Australian vineyards provides new and emerging information for vineyard managers on multispecies cover crops, native grasses and forbs (flowering plants).

The BPMG builds on existing industry knowledge to identify the tools and resources available and provides a step-by-step guide to improving ground covers in vineyards. With the intention that this BPMG is a practical guide for growers, the structure reflects the process required to achieve an improved ground cover system.

This consists of five steps, broadly defined as:

1. **The objective:** First steps
2. **Planning:** Deciding how you will achieve each task.
3. **Implementation:** Preparation, sowing and ongoing management.
4. **Monitoring:** What has been achieved and how to continue to improve?
5. **Tools and resources:** What information is available to help me make informed decisions?

This guide uses the term 'ground covers' to cover a range of techniques used to manage the vineyard floor. This includes the use of commercial multispecies cover crops and/or native grasses, forbs, and low-growing woody species. It includes more traditional ground covers in the mid-row, as well as the emerging technique of under-vine ground covers.

The term ground covers also includes the use of sown and managed crops, as well as allowing the development of volunteer plants that are then managed as a ground cover to benefit the vineyard. The focus of ground cover use in vineyards is based on their functional attributes. Rather than just passively allowing a ground cover to grow, we focus our efforts on achieving a desired outcome. The objective, therefore, needs to be well-defined and only then the process of designing, establishing, and managing the ground cover program can commence.

The Australian wine grape community is well advanced in its adoption and development of ground cover strategies. This solid base of information allows growers to extend their activities to achieve even greater stability and resilience in their vineyard systems through the integration of improved soil, ground cover, and biodiversity management practices.

The difference between dirt versus living soil

Traditionally, agriculture has been viewed through a two-dimensional lens of the soil and the crop. Too often, though, the soil was only seen as the 'dirt' that held up the plant.

Dirt is geology (sand, silt, and clay) and lacks an abundance of life.

Conversley, **healthy soil** teems with an abndance life (i.e., microbes including fungi, bacteria, archaea, protozoa, and nematodes) that plants need to grow and thrive.

While progress has been made on seeing soil as more than just the substrate crops grow in, there is still a gap in our approach. That gap is the 'ecology' of the system we are working in, and how the interaction of all its elements, including living organisms, contribute to the success of agriculture.

Our skills development has also traditionally focussed on – how can we grow a bigger, better crop? This has often been at the expense of nutrient integrity and plant health which can be objectively measured by assessing leaf brix using a refractometer or sending a sample to a laboratory for detailed assessment. Most wine growers now include consideration of ground covers and soil health as part of their overall management programs.

Historically, bare earth, or closely mown monoculture was mistakenly viewed by some growers as a 'good' system for production. This may be a case of aesthetics over function, or perhaps a misunderstanding of what is required to achieve optimal soil function, nutrient cycling, water holding capacity, grapevine health, and the overall resilience of the production system.

Do the images below depict the perfect ground cover program or the challenges of bare earth? The obvious lack of ground covers in the figures below contributes to higher temperatures, soil erosion and loss of topsoil, soil compaction, rapid loss of soil carbon, poor water infiltration, poor water holidng capacity, and poor soil microbiology.

Figure 2. An almond development (left) [Photo: Stuart Pettigrew], and mature vineyard devoid of ground cover vegetation, and with compacted soil (right) [Photo: Mary Retallack].

There has been a greater focus on 'regenerative farming', a term coined in the 1980s by the Rodale Institute, which has recently moved to the mainstream.

Broadly defined these practices are (Leask, 2020):

- **balancing soil nutrition limitations**
- **keeping soil covered**
- **minimising soil disturbance (cultivation)**
- **increasing plant and microbial diversity**
- **incorporating living roots into the farming system all year round**
- **integrating and managing livestock.**

Whilst the benefits of ground covers are widely researched and understood by most viticulturists, the challenge is translating this information to help achieve the objectives being sought.

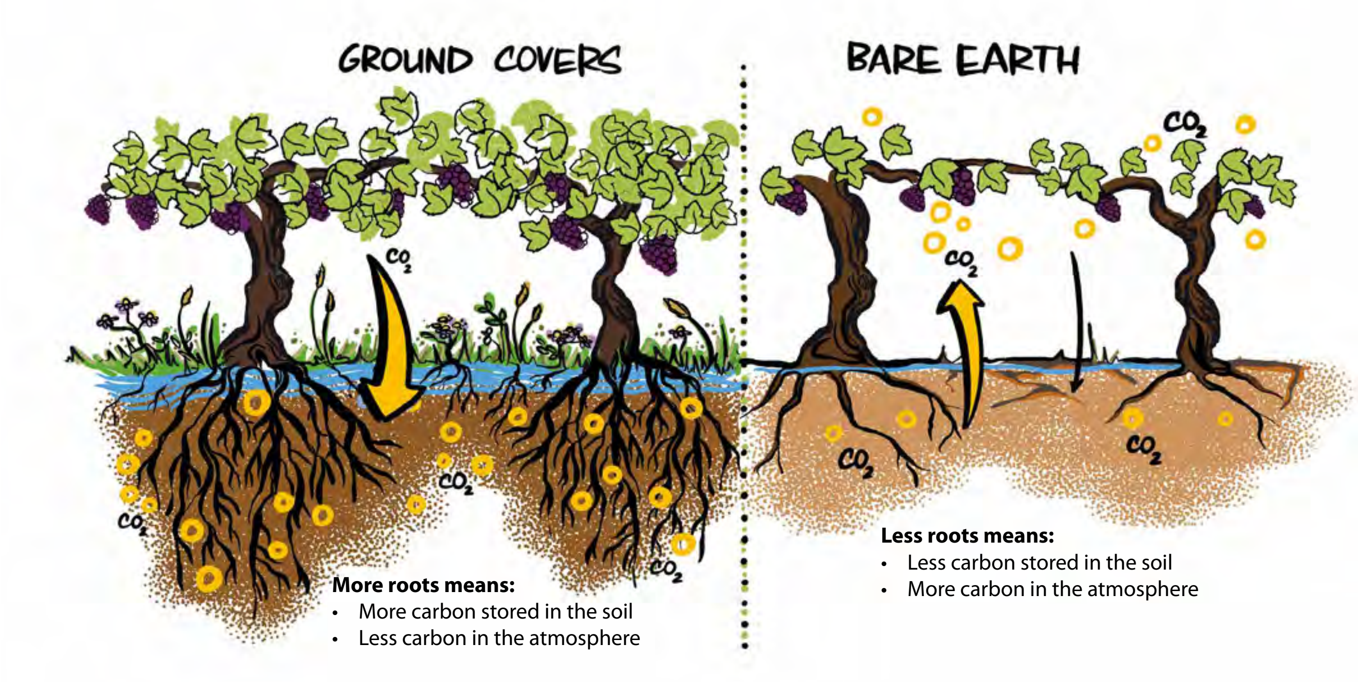


Figure 3. The benefits of ground cover plants versus bare earth in relation to carbon storage.

The National EcoVineyards Program advocates for the integration of functional ground covers into vineyard management systems.

The benefits of such ground cover management on vineyards are both direct and indirect.

- **Direct benefits** include improvements to soil and water management, weed control, pest and disease management, and can be readily measured in cost and input savings.
- **Indirect benefits** include improved soil carbon cycling (and potentailly storage), vineyard climate, improvements to grape quality and quantity, and may be more difficult to provide an economic value.

These benefits could also be broadly incorporated under the title of 'improving vineyard resilience'.

As discussed in this guide, the more easily measured part of improved vineyard resilience is in reduced utilisation and intervention.

By increasing vineyard resilience we can reduce inputs of water, synthetic fertilisers, pesticides, herbicides and, therefore, reduce the use of fossil fuels through reduced vineyard activities and reduced production of these inputs. The strategy may not be to only replace these inputs, but also increase their efficiency when they are used.

Step-by-step guide to ground covers

The approach to developing your ground cover management plan follows three key steps:

- **Why?** Deciding what you want to achieve
- **What?** Which species, where, and best approach?
- **How?** Implementing the plan

The final part of this BPMG looks at how to monitor your program and how to continually improve what you are doing.

Why?

There are many overlapping reasons to concentrate on improved ground cover management in vineyards. It may be that the vineyard manager wishes to address a major limiting factor for the vineyard, for example, improving soil integrity, or managing erosion, or reducing vine vigour, or improving the vineyard mesoclimate.

It is more likely that there are a range, or even a hierarchy, of reasons to bring this activity into focus. The table below looks at some of the main impacts that improved ground covers can have.

Table 2. Some of the benefits of functional ground covers

Soil	Water
• Improved soil structure (page 12) • Improved soil ecology (page 13) • Glomalin production and carbon storage (page 14) • Plant nutrient availablity and cycling, including organic matter (page 23)	• Erosion control (page 17) • Improved water holding capacity (page 17) • Increased and deeper infiltration (page 17) • Quality improvements (page 24)
Climate	**Viticulture**
• Reducing heat, reflection (page 19) • Cooling of vineyard – soils, vines, air (page 19) • ESG (environmental, social and governance) contribution, e.g. carbon/biodiversity credits (page 25)	• Improved vine health and resilience (page 18) • Improved vineyard production practices (page 19) • Quality, yield, and vigour management (page 20) • Managing weedy species (page 21) • Pests and disease control (page 22)

What?

Once the 'why' is resolved, the next set of questions for the manager to consider is the 'what'?

This will be driven by some core criteria:

- What are the aims (the 'why' above) and how this can be achieved?
- The region, site, and climate the property is in.
- The property and management approach, e.g. conventional, minimal input, regenerative, organic, biological, or biodynamic?
- The size, age, and health of the vineyard.
- Prior experience and current knowledge – what has worked, what hasn't and what do we need to try differently?

Within this framework, certain driving principles can be followed:

- Multispecies (polyculture) is better than single species (monoculture) in the long-term.
- Include a diversity of different 'functional groups' – grasses, herbs, brassicas, legumes, forbs, chenopods (a sub-family of amaranths), short and tall broad-leaved plants that are suited to your site.
- Start with one or two species from the grass, legume and tall and short broad leaf groups to promote functional diversity and fine tune your approach from there based on observation and experience.
- The longevity of perennials is better than annuals, but a mix is ok. You may wish to start with annuals and progress to perennials as soil health improves - ground cover benefits accrue over time.
- Are you intending to 'farm the whole hectare' – both mid-row and under-vine, how are different zones managed (mid-row, under-vine, trafficable lanes, etc.)?
- Will the focus be on natives, introduced, or volunteer/weedy species (which may be locally adapted but present other challenges)? What is the best for your site?
- Don't feel that you need to do everything at once or over the whole area. Start small and scale up as your confidence and knowledge grows.

How?

Once the why and the what have been decided, the components of the 'how' can then be determined. It is a common mistake when new management thinking is implemented - to be guided by what has been done before and existing resources that are available. To avoid limiting our thinking to the current paradigm, it is important to not focus on the 'how' until this final step.

It may be worth taking the opportunity at this point to make sure you have been open to all options for ground cover management and review your decision making throughout the 'why' and the 'what'.

Once this process is complete, the following considerations can be included:

- **What are your current resources?**

  Machinery, people, knowledge, how do you utilise these resources for maximum benefit?

  How do you fill the gaps in your current resources?

- **The key to a successful program is preparation.**

  Physical ground preparation is the main focus, and this is even more critical for native species that generally are slow to germinate, grow, and establish but are very hardy once mature. Potential weed competition needs to be managed. Also, preparing management programs, identifying constraints, and arming yourself with knowledge and helpful resources are also part of the preparation.

- **Progress your plan**

  Once you have decided on the type of ground cover that will best meet your needs, including when the best time is to sow, how will you sow it, who will do the work, and how does this impact on your other work programs, etc. all need to be checked off.

- **Grower experience will always tell you that patience is king!**

  It takes time, and some trial and error, to achieve a good outcome and may take more than one season. Learn from others but try your own ideas.

Once you have observed what works well over one or more seasons, start to scale up in managable stages.

THE OBJECTIVE: WHAT DO I WANT TO ACHIEVE?

Any changes in management practices needs to start with an assessment of what is the primary focus of the activity. Whilst the underpinning motivation is improving the profitability of the enterprise, this can be achieved in many ways. The following section outlines the main objectives that will drive this decision making and includes a discussion of how this has been achieved in different scenarios.

There will likely be more than one objective, but it helps to think of a hierarchy of objectives as compromises will likely be required. The aim is to find the main limiting factor that will be addressed by changes to ground cover management and build the overall program from there.

The weight of research on the best outcomes for soil health and vineyard benefits suggests that a ground cover system that has living roots all year round will generate the best outcomes.

EcoVineyards advocates for a 100% functional ground cover (and actively growing roots), 100% of the time where possible.

Whilst some growers still utilise a 'bare earth' strategy for vineyard floors, this is not a sound approach for resource management. A common justification for this approach has traditionally centred on reducing competition to vines for limited resources, primarily water, as well as to improve infiltration for rain.

A wide range of studies (refer to the following sections of this guide) and grower experiences have proved these assumptions are incorrect. Whilst in some regions and contexts a poorly selected and managed ground cover system may reduce available soil moisture, this is not uniform across systems.

The improved infiltration achieved by using appropriate ground covers, coupled with the improved soil structure and moisture holding of soils with higher organic matter, will in most cases compensate for any resource competition and retain soil moisture at depth when it is required by grapevines.

Beyond these resource questions, the increase in living root systems throughout the vineyard will help to produce and store carbon through the activity of improved soil biology, such as arbuscular mycorrhizae fungi (AMF), which produce glomalin. Glomalin acts as a 'super glue' helping sand, silt and, clay particles to stick together and to the organic matter that brings soil to life.

Ecosystem services

When discussing ground cover management, the benefits derived from this can be described as 'ecosystem services'. This terminology is used to describe a wide range of functional benefits, but a summary of these is provided below, drawn from Retallack (2018) and adapted to the context of this guide.

Provisioning services

- These relate to activities such as insectary plants which provide habitat for predatory arthropods (beneficial insects and spiders), biomass produced by the ground covers for carbon capture and mulch, or the nitrogen produced through the conversion activities of legumes in association with rhizobia bacteria.
- Provisioning services also relate to the wine grapes produced by a vineyard. In biodiversity terms, grapevines are a key part of the overall ecosystem to be managed.

Regulating services

- These are the benefits obtained from ground covers, such as minimising erosion from both wind and water, and the biological control of key pests and diseases. Mitigation of other climatic factors, such as extreme rainfall or extreme heat, is also achieved.

Cultural services

- This includes non-material benefits, such as recreation and aesthetic enjoyment.

Supporting services

- Another key element that improved ground covers will provide includes natural processes, such as the symbiotic relationship plants have with the surrounding microbiology, nutrient cycling, soil formation, and crop pollination.

Whilst the following sections do not refer directly to these four 'service groups' they are incorporated into the overall process of designing and developing ground cover plans.

They are also intrinsically linked to soil attributes (physical, chemical, biological) and functional biodiversity processes, which are covered separately in the suite of EcoVineyards best practice management guides.

Figure 4. Natural enemies and pollinators are found in association with insectary plants including ladybird beetles (left) and European honey bees (right) [Photos: Liz Riley].

Improved resource management

This section of the BPMG looks in detail at some of the benefits of improved resource management. One of the key drivers for changing vineyard ground cover management is to improve the efficacy and efficiency of resource use, whether this be natural resources, such as soil and water, or management inputs.

One of the key reasons for improving ground cover management is to improve soil condition and integrity. This includes soil physical, chemical, and biological impacts, and relates to improvements in soil organic matter and soil carbon, as well as the use of ground covers to manage erosion, water infiltration, and rainfall impacts.

Figure 5. Mid-summer in the vineyard with a small amount of crop residue remaining from the winter cover crop [Photo: Stuart Pettigrew].

Soil structure

Improvements to soil structure and physical properties are a key benefit of ground covers in not only viticulture (Abad et al., 2021a; BRI, 2022; Kesser et al., 2023; Vukicevich, 2019) but also in a broad range of cropping situations (Adetunji, 2020; Arias-Giraldo et al., 2021; Blanco-Canqui et al., 2015; Hao et al., 2022; Sharma, 2018).

Structure is important as soils need the capacity to breathe and store water. In fact, up to 50% pores is optimal for soil health (the other 50% is made up of mineral and organic matter).

Improved soil structure as a result of reduced soil compaction is regularly mentioned as one of the benefits of better ground cover management (Adetunji, 2020; Arias-Giraldo et al., 2021; Blanco-Canqui et al., 2015; BRI, 2022; Chapagain et al., 2020; Penfold and Howie, 2019; Pornaro et al., 2022; Wauters, 2023).

Bare compacted soils are often anerobic, bacteria dominant and susceptible to weedy species. Nature always fills a void where there is bare soil and starts the process of rehabilitation.

Grapevines and other perennial crops benefit from a greater fungi-to-bacteria ratio.

- Building new topsoil is possible with good ground cover management (Jones, 2002) via the liquid carbon pathway (Jones, 2008).
- The opposite is true of poor ground cover management. Under a bare earth scenario, it is possible to lose up to 150 tonnes of soil per hectare annually, but as low as 0.5 t/ha under unmanaged permanent pasture. With good ground cover management, topsoil can be added at a rate of more than 10 t/ha per annum.

For more ways on enhancing a range of fungi in soils please refer to the **EcoVineyards best practice management guide on soil health in Australian vineyards: Part B (biology)**.

Soil ecology

Their is a wide array of biology that can be found in healthy soils including bacteria, fungi, protozoa, nematodes, earthworms, arthropods, and many more. They include beneficial (predators) and antagonistic organisms (pests), but also many 'other' organisms that contribute to a balanced soil biology, like detritovores that help break down organic matter.

Figure 6. Soil macroorganisms commonly found in soil with high levels of organic matter [Photos: Mary Retallack].

Soil biology needs a diversity of living plant roots to survive and thrive; bare soils put microbes on a starvation diet and stops the soil ecosystem from fully functioning.

Multiple studies in vineyards show that an increased diversity of ground covers increases soil ecology (Arias-Giraldo et al., 2021; Blanco-Canqui et al., 2015; Castellano-Hinojosa and Strauss, 2020; Chou et al., 2018; Prommer et al., 2020). A meta-analysis undertaken by Kim (2020), found that ground covers impacted significantly on the abundance and activity of the soil microbiome by 27% and 22%, respectively, but less on diversity (2%). They also concluded that the integration of ground covers into other management practices was fundamental to successful improvements in the soil microbiome.

Recent research by the University of Adelaide found that microbial activity increased by more than double in soils with ground cover plants present compared to bare earth (Marks et al., 2022).

Castellano-Hinojosa and Strauss (2020) discuss the relatively limited research done on the impacts of ground covers in perennial crops when compared to annual crops. They also point out that the impact on the soil biome from annual cropping systems compared with perennial systems is very different, and that more research is required to understand the interaction of the microbiology with ground covers and those of perennial crops. The impact this has on interactions such as nutrient cycling needs to be better understood.

But what does 'improved soil biology' mean for vineyard management?

One key aspect is the increase in arbuscular mycorrhizae fungi, or AMF. This group of soil biology increase nutrient use efficiency, as well as soil carbon capture via the production of glomalin. The diversity of soil biology also contributes to improved disease control and can improve pest control by increasing the range of beneficial arthropods in the vineyard environment. An overall improvement in soil carbon – one of the outcomes of an increase in soil biology also dramatically increases soil water-holding capacity.

Soil carbon

The role of ground covers in increasing soil carbon is widely reported (Abdalla et al., 2019; Blanco-Canqui et al., 2015; Dinis et al., 2022; Fleishman, 2021; Marks et al., 2022; Prommer et al., 2020; Xu et al., 2020) amongst others.

Further, Novara et al. (2020) found that the greatest loss of carbon from vineyards occurred from erosion, which is reduced by improved ground cover management. Fleishman (2021) found that shallow carbon levels (0 to 40 cm) increased by as much as 50% using under-vine ground covers but did not impact on deeper carbon levels.

In Australia, (Marks et al., 2022) found cover crop-managed soil under-vine sequesters up to 23% more soil organic carbon (SOC) than the traditional herbicide practice over a five-year period of growth.

Xu et al. (2020) discusses the key role that the soil microbiome plays in increasing soil carbon associated with ground covers, and the increased abundance of the soil microbiome, adds significantly to soil carbon. Wagg et al. (2022) also discusses increases in carbon related to soil microbial diversity over time. This is an example of carbon storage via the breakdown of organic matter, but this isn't the quickest way to store soil carbon.

When plants are photosynthesising under optimal conditions, they produce exudates (sugars and carbohydrates) that feed soil microbes and they, in turn, help to cycle organic matter.

Similarly, mycorrhizal fungi produce glomalin, which can account for 27% of the carbon in soil, compared to humic acid which contributes about 8% carbon. That's more than three times the amount of carbon (Wright and Nicolson, 2002).

Under appropriate conditions, 30 to 40% of the carbon fixed in green leaves can be transferred to soil and rapidly humified, resulting in rates of soil carbon sequestration in the order of 5 to 20 tonnes of CO_2 per hectare per year.

In some instances, high soil carbon sequestration rates have been recorded where there were virtually no 'biomass inputs', suggesting that the liquid carbon pathway was the primary mechanism for soil building (Jones, 2008).

The liquid carbon pathway is a symbiotic relationship between mycorrhizal fungi and 90% of all plants. Plants will purposely produce extra carbohydrates (simple plant sugars) then exude that surplus into soil to feed fungi. Arbuscular mycorrhizal fungi (AMF), in turn, use the exudates to create their own sticky carbon exudate called glomalin.

Glomalin is critical in the formation of soil aggregates, which are essential in the creation of soil structure with pores for air and water storage. With the increased water-holding capacity that is brought about by increased soil carbon, a plant's photosynthetic capacity increases. This leads to more carbon being pumped down into the soil, an important feedback loop, all fuelled for free by the sun.

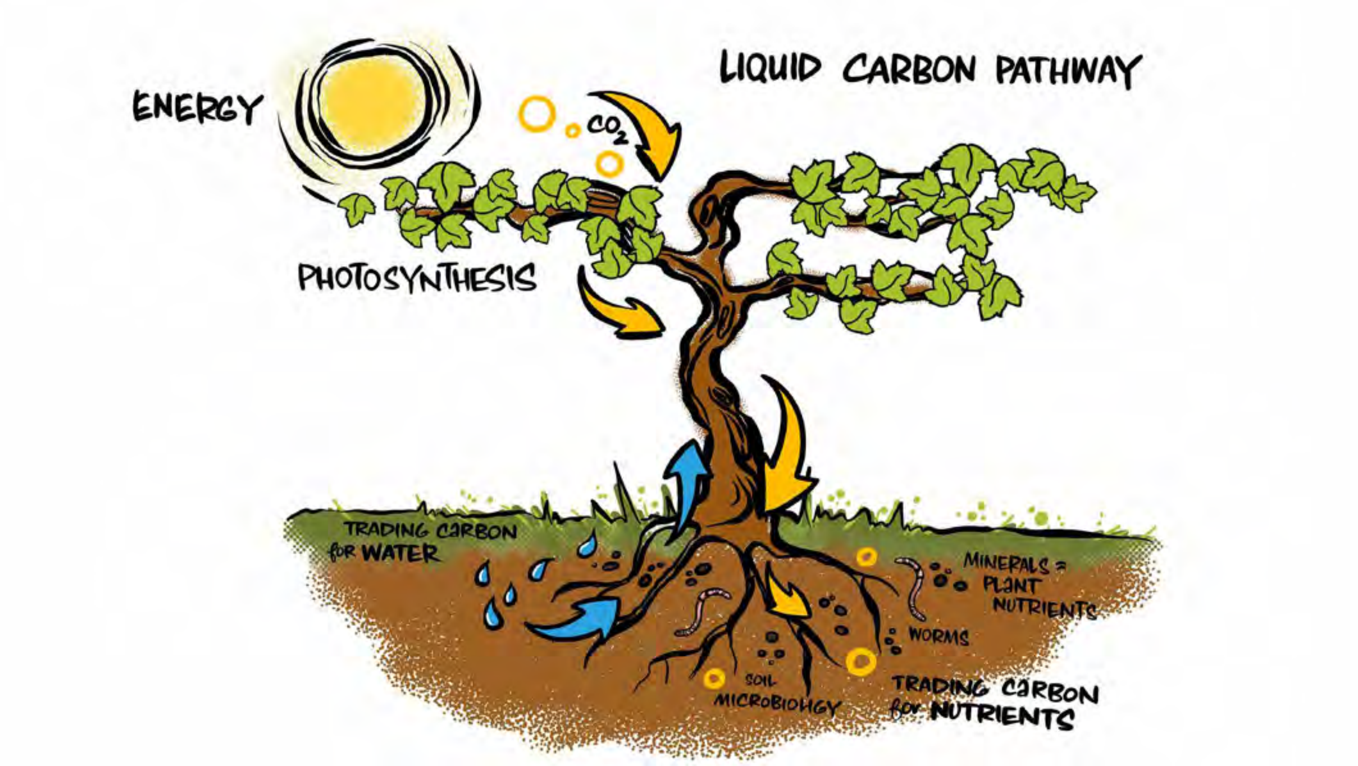


Figure 7. Soluble or liquid carbon pathway.

One of the key findings for vineyard managers to be aware of when designing their ground cover program is that an increase in the diversity of ground covers drives a greater increase in soil carbon compared to single species crops (Finney et al., 2016; Lange et al., 2021; Xu et al., 2020).

Two key findings for the role of ground covers includes:

- **Perennial (or year-round) green crops, as opposed to annual crops, have a much greater impact on soil development and soil carbon levels.**
- **Diversity of plant species is important as each plant, or group of plants, will contribute differently to the aggregate functionality of the ground cover community.**

In their systemic review of ground covers Hao et al. (2022) found a consistent improvement in soil carbon content, including microbial biomass carbon and particulate organic carbon.

Work undertaken by Jones (2018a), and further research detailed on the website Amazing Carbon, highlights the links between ground covers and their role in photosynthesis that directly increases soil carbon via the liquid carbon pathway. Photosynthesis and the 'liquid carbon pathway' are considered the most important drivers for soil building. Living hosts (green plants) provide soluble carbon and the necessary habitat for colonisation by mycorrhizal fungi.

A vineyard story about polyculture versus monoculture

A wine grower in the USA wanted to plant a multispecies mix but wasn't sure what each species looked like. So, he planted a few seeds of each species in separate pots, putting the remainder of the multispecies mix of seed in the larger pot on the left.

As you can see in the figure below, the pots on the right look chlorotic (with yellow leaves) and are struggling to grow well, whereas the multispecies mix of plants in the pot on the left are thriving.

Nature loves diversity and this creates more resilient agroecosystems.

Figure 8. Twelve cover crop species in pots prior to sowing in a vineyard, multispecies (left), and individual species (right) [Photo: Chase Thornhill].

Water – erosion, infiltration, drainage

Ground covers can dramatically reduce the amount of run-off, erosion, and soil loss in a vineyard, and have highly positive impacts on infiltration and, therefore, soil moisture storage. The amount of organic carbon in soil has a direct relationship with water-holding capacity.

A 1% increase in organic carbon can hold as much as 160,000 litres of additional plant-available soil moisture per hectare every time it rains (Morris, 2004). This will vary depending on the soil type, but the improvements will be considerable in all soils.

Despite this improved water-holding capacity, there may be a potential trade-off between the increased water use of ground covers and the improvements in water infiltration that come about from the installation of a ground cover (Daane et al., 2018; Novara et al., 2021; Vanden Heuvel and Centinari, 2021). What is important is the choice of ground covers to reduce this competition. It has been noted that sown ground covers also tend to use water prior to budbreak, which leads vines to explore different parts of the profile; and the choice of ground cover impacts where vines explore for water (e.g. deeper, or under-vine), but not necessarily compete directly (Celette et al., 2008; Lines, 2023).

Whilst a ground cover will use some additional moisture, the evidence points to a positive balance for the soil and, therefore, vines.

Rainfall impacts can include runoff, nutrient leaching, and impacts on vine growth and disease – all of which can be better managed with under-vine ground covers. Management of intense rainfall is a benefit of ground covers (Novara et al., 2021; Penfold and Collins, 2012a; Penfold and Collins, 2012b; Vanden Heuvel and Centinari, 2021). Improvements in infiltration and storage at depth are also a factor and can also help mitigate some of the water use by the ground cover (Blanco-Canqui et al., 2015; Celette et al., 2008).

Daane et al. (2018) found that native grasses improve soil water content and that deep-rooted native grasses increase water infiltration and reduce evaporation.

Similar, results have also been observed in Australia with the use of wallaby grasses under-vine where there has been an improvement in organic matter and water holding capacity at depth (Dan Falkenberg, Eden Hall Vineyard, *pers. comm.*).

Small water cycle

Ground covers can also encourage a small water cycle; where there is greater humidity, there are living plants present. Water is transpired by plants during the day, often settling back at ground level as fog and/or dew on cold mornings, whereas bare soil tends to remain dry as the moisture is lost due to evaporation.

It is a bit like boiling a pot of water on the stove. The analogy is that bare soil represents a pot without a lid and the boiling water vaporises until the pot is dry, but a soil covered by living plants (the pot analogy this time with a lid) has a protective layer that reduces the amount of moisture lost to the atmosphere. Ground cover matters!

Impacts of climate change

References to managing the impacts of climate change are found throughout the literature related to ground covers (Dinis et al., 2022; Naulleau et al., 2021; Oliveira et al., 2022). The ability of ground covers to acquire atmospheric carbon and store it in the soil profile are also discussed in the literature. A podcast titled 'Rebuilding the soil carbon sponge' discusses the concept that the central argument to cooling the atmosphere is rebuilding soil carbon (Jehne, 2022) rather than decarbonising.

One of the aims of improved ground cover management is to improve the physical resilience of a vineyard system. This includes reducing the impacts of extreme weather events, such intense rainfall or mitigating the impact of extreme heat on grape quality by modifying the vineyard environment. Improved ground cover management results in improved biodiversity in the vineyard environment which, in turn, contributes to improved resilience. Resilience is fostered by biodiversity and ecosystem services (ES). Winter et al. (2018) found that: "Across studies, extensive vegetation management resulted in a 20% increased biodiversity and ES provision."

The resilience of a system describes its capacity to reorganise after local disturbance (Tscharntke et al., 2005), or in response to environmental changes (Oliver et al., 2015).

'4 per 1000' initiative

It is well known that human activities emit huge amounts of carbon dioxide (CO_2) into the atmosphere, which enhances the greenhouse effect and accelerates climate change.

What is less well known is that every year, about 30% of this carbon dioxide is recovered by plants through photosynthesis and via plant relationships with soil microbes can be stored in stable forms of organic carbon.

Similarly, when plants die and decompose, living organisms in soil, such as bacteria, fungi, or earthworms, transform them into organic matter. This organic matter which is rich in carbon retains water, and nutrients that are essential for plant growth. Collectively, plants represent enormous potential for carbon storage.

The world's soils contain two to three times more carbon than the atmosphere. If the level of carbon stored by soils in the top 30 to 40 cm of soil increased by 0.4% per year, the annual increase of carbon dioxide (CO_2) in the atmosphere would be significantly reduced.

Visit the '4 per 1000' website and watch this introductory video to find out more.

Figure 9. '4 per 1000' initiative sees soils as crucial to tackling climate change.

Viticulture improvements from ground covers

Gliessman (2016) developed a multi-level description for improving farm production practices, and it is worth looking at this in the context of ground cover management.

The first four levels of his approach fits with the aims of the EcoVineyards program and specifically ground cover management and include:

Level 1. **Increase the efficiency of industrial and conventional practices to reduce the use and consumption of costly, scarce, or environmentally damaging inputs.**

Level 2. **Substitute alternative practices for industrial/conventional inputs and practices.**

Level 3. **Redesign the agroecosystem so that it functions based on a new set of ecological processes.**

Level 4. **Re-establish a more direct connection between those who grow our food and those who consume it.**

The following section looks at how a renewed approach to ground covers can help vineyard managers progress through Levels 1 to 3 in this hierarchy. Each vineyard involved in the EcoVineyards program, or beginning to implement this BPMG, will likely be on the path through Level 1 or 2 and moving towards aspects of Level 3 by redesigning and enhancing the functional ecosystem in their vineyards.

Whilst Level 4 probably sits outside the scope of this guide, it is worth considering the potential value chain impacts of improving production practices using more ecologically focused and regenerative approaches, such as ground cover management. These are also part of the 'cultural services' mentioned previously on page 11.

Markets are becoming more interested in the way food and discretionary products, such as wine, are produced, and the role of vineyard practices is increasingly important.

There is the opportunity to showcase Australia's natural flora in vineyard and for the associated wine promotion to stand out in a crowded international marketplace. Not only are these plants functional and locally adapted, but they also look great too!

Vineyard mesoclimate

The vineyard environment is heavily impacted by ground cover management. Reducing the heat and reflective impact on grapes is a key role of a ground cover. Vineyard temperatures, both heat and cold, will impact on the performance of the vineyard, including grape production but also general biodiversity, pest control, and disease impacts.

Whilst higher humidity related to ground covers has the potential to increase disease risk, the reduction in rain splash reduces the potential ground-to-vine transfer of spores, such as those of downy mildew; the increased habitat for predatory arthropods, including as fungi-eating ladybirds, will also help to offset these concerns. In addition, it is hypothesised that AMF symbiosis may enhance plant defences against insect herbivores and pathogens (Frew et al., 2024).

The ability of a vineyard to absorb extreme weather events will be improved through the utilisation of a better ground cover management system. This includes the impacts of rainfall (Vanden Heuvel and Centinari, 2021), as well as extreme heat, frost or cold (Dinis et al. 2022).

Weed control

Ground covers provide a direct economic benefit through improved weed control in vineyards (Baumgartner et al., 2008; Blanco-Canqui et al., 2015; Penfold and Collins, 2012c; Pornaro et al., 2022; Steinmaus et al., 2008), including the use of under-vine ground covers (Abad et al., 2020; Guerra et al., 2022; Jordan et al., 2016; Penfold, 2018; Penfold and Howie, 2019).

Guerra et al. (2022) found that the use of endemic or native species was important in areas of low rainfall, and that when established (> 70% cover), weed suppression was as high as 95%. Importantly there was no impact on vine yield or vigour.

The low impact on vigour through the selection of suitable species is supported by (Jordan et al., 2016; Penfold, 2018). However, Karl et al. (2016) found significant reduction in vigour, and that glyphosate control was more profitable. It is important to understand the context of these studies and the status of vine health, as often a vineyard in decline due to trunk disease and other factors may struggle initially as perennial ground covers establish but little or no yield penalty is observed by year two or three.

These findings highlight the need to carefully select the under-vine species to reduce this potential yield impact during the establishment phase. Other considerations are the timeframe for assessment, with some benefits accruing over a longer period of time, as well as the health and/or vigour of the vines in the trial site.

Blanco-Canqui et al. (2015), in their review of ground covers, found a wide range of results in weed suppression, again highlighting species selection and management for different situations as an integral part of successful weed control. Vukicevich (2019) also found more impact on vine vigour when under-vine ground covers were used in a young (two-year-old) vineyard.

Several papers also provide an overview of the management of ground covers for weed suppression in broadacre and other crops (Lemessa and Wakjira, 2015; Osipitan et al., 2018; Osipitan et al., 2019; Wauters, 2023).

When well-chosen for the location, and with appropriate management, the general findings are that ground covers can supress weeds without the need for herbicides.

In Australia, mature stands of mixed species of wallaby grasses can supress most weedy species in the vineyard including wire weed, salvation jane, and evening primrose (Dan Falkenberg, Eden Hall Vineyard *pers. comm*).

The role of ground covers to help control herbicide resistant or difficult-to-control weeds is discussed in (Guerra and Steenwerth, 2012; Hall et al., 2020; Osipitan et al., 2018; SARE, 2019).

Lines (2023) also mentioned the role of under-vine ground covers in controlling fleabane in inland region vineyards that tends to thrive on bare soil without any shade. Guerra et al. (2022) highlights that a part of the EU Green Deal is to use ground covers as part of managing herbicide-resistant weeds.

Figure 10. Young vineyards can benefit from improved ground cover management to reduce heat, wind damage, and help supress weeds [Photo: Stuart Pettigrew].

Weedy species as indicators of soil health

Weedy species are often referred to as plants located in an undesirable location. But what if that plant provides an indicator of soil health and is performing a vital role in healing the land? Many weeds act as accumulators of minerals in deficient soils and when they die and decay, the minerals are returned to the soil in a form that is plant available.

Weedy species are an important part of ecological succession. They are also known as pioneer or early succession species. They tend to fill a void where there is bare soil and provide insights regarding soil health.

For example (Retallack, 2022) highlights the function of some commonly observed weedy species:

- Weedy species that have deep **taproots** (*Cichorium intybus*, chicory; *Plantago lanceolata*, plantain; and *Taraxacum officinale*, dandelion) **generally indicate soils that are compacted**, preventing plants with more fibrous roots from establishing. These taproots break up compacted soil layers and as they decompose, create pathways for water, nutrients, and more fibrous roots systems to follow.
- Weedy species that have fine, spreading, and **fibrous root systems** are likely present to **stabilise sandy soils** that are loose and erosive. They help to reduce erosion on slopes and banks.
- Plants with **thorns** (i.e., *Tribulus terrestris*, caltrop) or that are poisonous to animals (i.e., *Echium plantagineum* Paterson's curse/salvation jane; *Lolium perenne*, perennial ryegrass; *Hypericum perforatum*, St John's wort) **protect ground cover plants from being over-grazed** by herbivores.
- **Legume** roots (i.e., *Cytisus scoparius*, scotch broom; *Ulex europaeus*, gorse; *Lupinus* sp., lupin; or *Vicia* spp., vetch) have nodes that contain **nitrogen-fixing bacteria**.

For more information about weedy species please refer to the **EcoVineyards fact sheet: Weedy species or early succession pioneer plants... what do they tell us about our soil?**

Pests and diseases

Improving the diversity of ground covers in a vineyard is linked to improved pest and disease control (Abad et al., 2021b; Blanco-Canqui et al., 2015; BRI, 2022; Danne et al., 2010; Guerra and Steenwerth, 2012; Hall et al., 2020; Pornaro et al., 2022; Retallack, 2019; Sáenz-Romo et al., 2019; Thompson, 2012). Most of these studies look at the general value of ground covers in improving pest and disease control, although specific studies looking at individual pests and diseases are also found (Gonçalves et al., 2019; Sandanayaka et al., 2018).

Native ground covers were shown to provide greater pest control through predation and parasitism than non-native species (Danne et al., 2010), although this comes with the risk that some ground covers may also house a greater number of potential pests. Overall, the use of ground covers and native plants that are endemic and will self-propagate can have greater benefits (Daane et al., 2018; Gonçalves et al., 2019; Retallack, 2019).

The difference in predatory arthropod abundance between sown and tilled earth has also been discussed. Sáenz-Romo et al. (2019) found carabid (predatory ground beetle) abundance under the cover crop treatments was approximately three times higher compared with that under the tillage treatment. Reiff et al. (2021) found small but positive effects of spontaneous vegetation compared to sown ground covers on the level of predation of grape berry moth.

Irvin et al. (2018) found improvements in beneficial insects in ground covers, but also focussed on the dispersal of these across rows. They found that marked individuals were found up to 30 metres from the ground cover, with implications for how the ground covers are established and managed.

Daane et al. (2018) also mentions the role ground covers can play in the main crop, and if it reduces the susceptibility of the crop to pest impacts. Some of the impact of reduced disease impacts is attributed to reduced vigour imparted by the ground cover (Abad et al., 2021b; Griesser et al., 2022; Guerra and Steenwerth, 2012; Penfold and Collins, 2012b).

The role of ground covers as part of an integrated program was highlighted by Geldenhuys et al. (2021) in a study of different ground covers and management regimes. They found, *"that the maintenance of dense and diverse ground covers is a strategic way to enhance vineyard arthropod diversity where other management practices are already implemented sensitively."*

Similarly, Retallack (2019) found that it is possible to increase the functional diversity of predatory arthropods by more than 3x when low-growing, native, evergreen shrubs are present versus grapevines only, and increase the net number of predator morphospecies by around 27% when wallaby grasses, *Rytidosperma* spp. are planted in combination with grapevines.

To find out more about the predatory arthropods found in association with a range of ground cover plants please refer to the **EcoVineyards best practice management guide on functional biodiversity in Australian vineyards.**

Nutrition

The complexities discussed in relation to soil water are also true for soil nutrition. There is a trade-off, or management decision, that needs to be made between the potential use of nutrients by the ground cover and the myriad other benefits, such as nitrogen fixing by the rhizobia bacteria found in association with legumes, nutrients being made plant available by soil biota found in assocation with plant roots and reduced leaching of nutrients through improved ground cover management.

Abdalla et al. (2019) undertook a detailed review of ground covers related to nitrogen leaching among other topics. The review found that ground covers significantly reduced nitrogen leaching, and the use of legumes could be beneficial to nitrogen levels and the production of the main crop. Kesser et al. (2023) also discusses the role of ground covers in the acquisition of carbon and nitrogen by the soil from the atmosphere, and that increases in above-ground biomass increases this acquisition.

This work also references other research that looks at the negative impact that herbicides and bare earth have on arbuscular mycorrhizae and, therefore, a reduction in the ability of associated plants like grapevines to acquire nutrients from the soil via the mycelial networks and conversion of nutrients into plant available forms by soil borne microbes that would otherwise be present.

Research on the role of ground covers on soil nitrogen in California by Steenwerth and Belina (2008a) also found, "...ground covers enhanced soil N dynamics and microbiological functions of N mineralization...", even when not using legumes.

Jones (2021) also comments that it is possible to provide an abundance of nitrogen by using multispecies mixes rather than relying just on legumes.

Lines (2023) highlighted that when using under-vine ground covers, the inclusion of legumes showed reduced impact when assessing the impact on vine growth. This is due to the trade-off between competition from under-vine ground covers and the acquisition of atmospheric nitrogen.

Less research is available on other nutrients, although the Jena Experiment looked at phosphorus cycling over its long term studies, but found weak connections between ground covers and P-cycling (Weisser et al., 2017). Other studies also confirmed that little impact could be found on phosphorus with different ground covers, or for other main elements including potassium (Abad et al., 2021a).

The Jena Experiment is a German research project, focussed on biodiversity-ecosystem functioning.

According to the project website, despite a broad consensus of the positive biodiversity-ecosystem functioning (BEF) relationship, the underlying ecological and evolutionary mechanisms have not been well understood.

The Jena Experiment is aimed at filling this gap through experimental and analytical approaches in one of the longest-running biodiversity experiments in the world (running since 2002). The central aim of the research unit is to uncover the mechanisms that determine BEF relationships in the short- and long-term. View this short video to find out more.

The choice of ground covers will clearly play a role in the impact on nutrition. A study of a vineyard in the Rioja region of Spain by Pérez-Álvarez et al. (2015) compared three treatments – barley, legumes, and tillage to see the impact on soil nutrition and vine performance. As would be expected, the barley reduced soil nitrogen (but not other elements) whereas legumes increased nitrogen.

Productivity and quality

The impact of ground covers on grape production, both fruit quality and quantity is widely discussed in the literature. It has been identified as one of the limiting factors in the broader uptake of ground covers. Results of research, as well as anecdotal evidence from grape growers both in Australia and internationally, provide a mixed picture. But, more importantly, this goes to the heart of the decision-making for vineyard managers. It may be that reducing excessive vine vigour to improve wine attributes is the intention of a ground cover plan. In this case, the impact on grapevines is the starting point. Muscas et al. (2017) stated, *'Consequently, utilizing competitive ground covers, while reducing yields, would improve must quality and reduce pest development.'*

Sweet and Schreiner (2010) found that mid-row covers crops, *"did not alter shoot growth, pruning mass, leaf water potential, fine root density, or colonization of roots by AMF and did not affect yield, cluster weights, juice soluble solids, pH, or titratable acidity."*

Ensuring plants are locally adapted was found to be important in reducing the impact on vine vigour or yield (Daane et al., 2018). The role of legumes in improving nitrogen fixing into the rootzone was seen as reducing any vigour trade-off that the ground cover may have (Steenwerth and Belina, 2008b). Similarly, the improvements in water infiltration and reduced evaporation can also lead to a net benefit from under-vine ground covers (Blanco-Canqui et al., 2015; Celette et al., 2008; Daane et al., 2018; Novara et al., 2021; Vanden Heuvel and Centinari, 2021). Improvements in soil carbon and organic matter may also provide net benefits (Fleishman, 2021; Lange et al., 2021).

The main point to consider in the impact on production is, 'what is the ultimate intention of the role of ground cover changes?' It may be that reducing production whilst also reducing production costs may provide a stronger bottom line for the grower.

Under-vine

A trial on drip irrigated Merlot vines in the Navarra region of Spain by Abad et al. (2020) found good weed suppression yet no impact on yield, cluster weight, berry weight, or on grape composition when under-vine ground covers containing clover were used.

Several studies also discussed the potential of using under-vine ground covers to manage excess vigour to improve management, as well as grape quality (Centinari et al., 2016; Chou and Vanden Heuvel, 2019; Fleishman, 2023; Retallack, 2019). Studies have shown that species selection gave very different results, particularly in Chou and Vanden Heuvel (2019) where chicory (which has a long tap root) caused heavy vigour reduction (64% percent pruning weight reduction), but native vegetation showing little impact. This supports the observations of other studies detailed above that show different outcomes for ground covers.

Conversely, a well-designed ground cover program has been shown to have minimal or no impact on grape production. Jordan et al. (2016), in a study of cool climate, rain-fed Riesling grapes in New York State, found, *"Among the four under-vine treatments, no significant differences were found in measures of vegetative growth, yield, petiole nutrient concentrations at veraison, or predawn and midday stem water potentials."* In the Australian context, results were also mixed but tended to show limited impact on production over the longer term from under-vine ground covers (Kesser et al., 2023; Penfold, 2018; Penfold and Howie, 2019).

Assessing the benefits of a ground cover program using available references provides a mixed picture. Results are complicated not only by the range of benefits that can be accrued, but also the complexity of the vineyard system. The objective of the program also affects the view as to whether the outcome is positive or negative. For example, a reduction in vine vigour may be the aim of a ground cover program in an overly vigorous block but could be a negative in another block aiming for high production.

Other considerations

The final group of objectives relate to the range of benefits that can be accrued from improved ground cover management, but do not impact directly on the viticulture.

However, some of these will add to the direct monetary benefits of improving ground covers:

- **aesthetics (or amenity) values**
- **benefits in the market value chain**
- **carbon or sustainability credits**
- **other environmental benefits.**

The value of improved market outcomes can only be assessed by each grower at an individual property level. Similarly, with an improvement in the aesthetics or amenity value, this is something that can either be attributed an actual value, or it may serve as a motivation for each grower to continue with the ground cover plan. If it improves the enjoyment of working on the property, this is still a real value for the changed approach!

An interesting perspective on the benefits of ground cover is the reduction in potential groundwater pollution from fungicides (Ortega et al., 2022). Although the results were mixed, the study found a reduction in fungicide activity in soils. This suggests that under-vine ground cover strategies could be important for fungicide management into soils, and the negative impact that fungicides applied to the grapevine canopy may have on soil fungi.

Environmental and biodiversity credit schemes

There are a range of environmental and biodiversity credit schemes that exist (Australian Government, 2023; Biodiversity Credit Exchange, 2023). Whilst EcoVineyards does not promote any of these specifically, they may be part of the economic assessment each grower can make. What is important in most of these programs is to ensure that a baseline of data is collected.

For soil carbon, this may require a different set of data compared with the samples normally taken for vineyard nutrition monitoring. Not collecting the correct data prior to applying for such credits may make the process more difficult or impossible.

There is also the consideration of the type of vegetation that is eligible (trees must have the potential to reach a height of at least two metres and provide crown cover over at least 20% of the land), the commitment required (normally 25 or 100 years) and the inherent risk that if your carbon levels decline, you may be required to make up any shortfall in carbon credits over the term of your contract.

If you would like to find out more about carbon markets, please refer to the AgriFutures and Australian Farm Institute's **Carbon opportunity decision support tool**.

PLANNING: DECIDING HOW YOU WILL ACHIEVE EACH TASK

The range of benefits and impacts discussed above will help resolve the question of 'why' changes are desirable. Once this is resolved, the next set of questions for the manager to address looks at the 'what?'.

This will be driven by three main set of criteria:

- **The objectives of the program (based on the discussion from the previous section).**
- **The region, site, and climate the property is in.**
- **Prior experience and current knowledge – what has worked, what hasn't and what do we need to try?**

Within this framework, there will be several key decisions to be made, including what to plant (multispecies, annuals versus perennials, natives, introduced, or endemics), when to plant and what resources are required? The following information helps develop the overall ground cover plan to be implemented.

Current situation

In any management decision, knowing where the current management is at is very important.

Suggested questions to cover in an assessment plan:

- **What are the details of my site – soils, climate, geography?**
- **What I have I done before and what lessons can I take from this?**
- **Can I make a cost-benefit analysis?**

Ground cover plan

Once the objectives and situation analysis have been completed, an implementation plan can be developed. This will include:

- What is the overall approach – separate management zones for mid-row versus under-vine?
- Will I look to a system of sowing annual crops as ground covers, managing endemic/volunteer species, establishing native species, a combination of these?
- Will this comprise a trial area (trial design) or am I confident to do a full implementation?

Vineyard zones

A key decision regarding implementation of a ground cover program is to understand the different management zones of the vineyard. For ground cover management, these are divided into three distinct zones: mid-row, under-vine and boundary, or areas surrounding the vineyard.

Mid-row

The mid-row area is the zone we traditionally think of for ground covers. In many vineyards this is either sown with introduced species (increasingly native species) or is allowed to grow with volunteer species and slashed to maintain a clean mid-row area. This area also includes the traffic lines, or wheel tracks, from machinery work, which is a sub-zone of the mid-row that sometimes requires additional management.

Under-vine

Managing ground cover in the under-vine zone is a relatively new strategy used for purposes such as herbicide reduction, insectary, climate resilience, and to manage crop attributes.

Some growers sow an annual green manure cover crop planted up to the butt of the vine in every second row (alternative rows planted each year) and slashed in spring using an undervine mower, so there is no delineation between mid-row and under-vine. The ground cover area (under-vine and mid row) is managed in the same way.

For more insights on growing multispecies cover crops please refer to **Grower insights: Steven Faulkner, Oakridge Wines.**

Figure 11. Cover crop planted up to the butt of the vine, Yarra Valley, Victoria [Photo: Steve Faulkner].

Boundary

Ground covers in the areas immediately outside the vineyard boundary, including headlands, fence lines, and boundary areas, also play a role in biodiversity, vineyard management and the logistics of access to the vineyard. It is an area that traditionally has not had as much attention paid to it as the areas inside the vineyard perimeter.

What to plant?

Once you have decided on the zones to be managed, the decision on what to plant can be considered.

Benefits of multispecies ground covers

A recurring theme in the literature is the use of multispecies ground covers to improve outcomes (Chapagain et al. 2020, Elhakeem et al. 2019, Finney et al. 2016, Jones 2018). This requires a mix of species that provide different functions (or traits) to achieve an improved outcome.

Choosing the right species to include in a multispecies mix is also important. Choosing poorly adapted species may result in failure of part of the mix, and the emergence of a dominant, or even a weedy species. This is highlighted in Chapagain et al. (2020) where they state, *"an emerging concept is the importance of selecting ground cover species with functional complementarity rather than simply increasing the number of species."*

A key attribute of species diversity relates to 'asynchrony' of the functional groups, when events occur at unrelated times. This refers to the fact that plants of different species and growth habits can respond to different climate or ecological impacts, resulting in greater system stability (Craven et al., 2018, Gross et al. 2014, Hall et al., 2020, Oliveira et al. 2022, Tilman 2014, Vogel et al. 2019, Wagg et al. 2022).

This also creates redundancy and resilience in the system. If one species is not suited to the prevailing conditions, it is likely that another species in the mix will do well and can continue to provide important ecosystem services.

For example:

- Increasing the number of species in a stand of plants also increased ground cover biomass (Finney et al. 2016, Gross et al. 2014, Lange et al. 2021, Prommer et al. 2020).
- Greater diversity of species also showed increases in soil carbon (Prommer et al. 2020, Xu et al. 2020).
- The longevity of species was also improved under more diverse crops (Roeder et al. 2021).
- Long-term projects, such as the Jena Experiment, have shown increasing benefits over time from multispecies ground covers (Wagg et al. 2022, Weisser et al. 2017).
- In a data synthesis looking at biodiversity and ecosystem services, Dainese et al. (2019) concluded, *"that up to 50% of the negative effects of landscape simplification on ecosystem services was due to richness losses of service-providing organisms, with negative consequences for crop yields".*

The common theme in this work is that establishing a more diverse ground cover delivers outcomes that are greater than the sum of the parts.

Figure 12. Multi species cover crop blend, Yarra Valley, Victoria [Photos: Steve Faulkner].

Functional groups

Deciding on the functional trait(s) required for the ground cover is the first step in determining the species composition. Vukicevich (2019) notes that the various functional groups will compete differently with the vines, and this needs to be considered. With respect to soil biology, the overall lowest species richness was recorded in vineyards with grasses as ground covers compared with vineyards with ground cover mixtures or spontaneous vegetation cover (Baumgartner et al., 2008). Often, grasses will dominate a mix of grasses and forbs. Seeded crops also tend to have lower biodiversity compared with spontaneous vegetation (Hall et al., 2020; Sáenz-Romo et al., 2019).

A good starting point when developing a ground cover mixture is to look for different functional groups, for example:

- **Grasses (cool and/or warm season)**
- **Legumes (cool and/or warm season**
- **Tall and short broad leaves (cool and/or warm season)**
  - **Brassicas**
  - **Chenopods (a sub-family of amaranths)**
  - **Other families.**

Generally, aim to have at least four of the above functional groups represented in a multispecies mix and at least two species of each where possible.

If the decision is to proceed with native species, then the diversity of seed available in the mix may be less, but it is still possible to combine locally adapted species for a more diverse ground cover. For more information on native species see Section 3: Native grasses and forbs in vineyards.

There is no need to develop a 'one-size-fits-all' approach. It may be that different zones of the vineyard can have a different approach, for example, native grasses in the mid-row but introduced species in the under-vine zone (or vice versa).

Another option is to sow different species mixes in alternate rows. Irvin et al. (2018) found that natural predators will disperse up to 30 metres from the source crop, meaning that an insectary mix may only be needed in a few rows of each vineyard.

Similarly, in some New Zealand vineyards, the use of flowering buckwheat in one row in ten (25 m) reduces leafroller populations to below economic thresholds (Bernard and Wratten, 2007).

If a native species is to be sown, the time taken to establish this may mean a different crop is grown in some rows while in the other rows the native species is established, from which seed can be harvested for expansion beyond the existing rows as they mature in year two. Trialling multiple species in separate rows allows for trial and error at the same time, rather than in consecutive seasons.

Geldenhuys et al. (2021) found that the maintenance of dense and diverse ground covers is a strategic way to enhance vineyard arthropod diversity where other management practices are already implemented sensitively. This highlights that minimal adjustment of management practices can greatly benefit farmland biodiversity conservation and is in keeping with the ethos of the concept of a biosphere reserve.

Native or endemics or introduced species?

Several studies discuss the benefits of using native and endemic species, adaptation to local conditions (Daane et al., 2018; Danne et al., 2010; Ferrari and Parera, 2015; Hall et al., 2020; Penfold, 2012; Retallack, 2019). In both the case of volunteer species and natives, the adaption to local conditions is seen as a key benefit. Endemic species that have performed well in local conditions (which can include native species) may also have benefits in competition with less desirable weedy species, resilience to local conditions, and improved soil coverage (Neri et al., 2022).

The use of introduced species increases the range of functional traits that may be available in a multispecies mix. This is a sound management decision, but the negative impacts of such species, such as their capacity to outcompete desirable native species or their capacity to 'escape' as weeds, needs to be considered carefully.

Research also highlights that aggressive species such as *Phalaris* sp., phalaris; *Paspalum* sp., paspalum; *Dactylis* sp., cocksfoot; and *Festuca* sp., fescue should be avoided for under-vine ground covers (Guerra and Steenwerth, 2012; Karl et al., 2016; Lines, 2023) along with species that grow greater than 40 to 50 cm and create significant bulk to avoid encroachment into the grapevine canopy.

Perennials or annual

Another topic area is the use of perennials versus annuals. Annuals will readily seed and establish but will need to be sown in subsequent years. Perennial species may take longer to establish but will persist in the landscape for potentially decades or much longer if conditions are conducive. In some cases, they are a once off cost.

The general consensus is that as benefits accrue over longer periods with ground covers (Roeder et al., 2021; Wagg et al., 2022; Weisser et al., 2017), and therefore, perennial species may be preferred (Lines, 2023; Miglécz et al., 2015; Penfold, 2018). Perennial plants also contribute more to soil carbon (Jones, 2018a) and provide greater benefits for soil ecology by not disturbing the balance of root activity, such as those colonised by AMF. This is particularly the case when considering the need to reduce machinery and soil disturbance when preparing land for resowing crops. They may cost more upfront to sow, but there are cost savings for every year you do not need to intervene to establish a new annual cover crop.

Figure 13. Residual cereal cover crop (left) [Photo: Steve Faulkner] and mature perennial wallaby grass can produce >10x the seed compared to the original seeding rate (right) [Photo: Dan Falkenberg].

Arbuscular mycorrhizal fungi (AMF)

There have been several mentions of arbuscular mycorrhizal fungi, or AMF, in this and previous guides. These are a group of soil biology that contribute to nutrient cycling and improve efficiency of grape growing. Trouvelot et al. (2015) reviewed the ecosystem services of arbuscular mycorrhizal fungi for grapevine production.

They found several major factors to consider, including:

- **AMF increase grapevine growth and nutrition via better access to soil nutrients (especially nitrogen and phosphorus).**
- **AMF increase the tolerance to abiotic stresses, such as water stress, soil salinity, iron chlorosis, and heavy metal toxicity.**
- **AMF protect against biotic stresses, such as root diseases.**
- **AMF produce glycoproteins and a dense hyphal network that increases soil stability and save soil nutrients up to 14% of the grape production income.**
- **Phosphorus fertilisation reduces mycorrhization.**
- **Using herbaceous plants as ground covers favours arbuscular mycorrhiza fungi.**

Several species, such as brassicas, can have a negative impact on this group of soil biology as they are one of the few plant groups that do not rely on a symbiotic relationship with AMF, so should be used with care. Brassicas have the advantage of providing nematode control, but de Souza and Santos (2018) found that some brassicas can lead to a reduction in the size of effective AMF populations, and this may impact on the future success of sown annual crops.

Similarly, it is important to consider the reason why brassicas are being used if they are beig routinely planted as to help control damaging populations of root-knot nematodes, as this may be a short term fix. If the underlying soil health is unbalanced this may result in the dominance of plant parasitic nematodes. Addressing underlying soil health and providing conditions for a diversity of soil biota can help to control damaging populations of parasitic nematodes via natural biocontrol.

The impact of AMF should be a major contributor to the decision making around the species to be included. Similarly, consideration should be given to the frequency and types of fungicides that are used in the vineyard as they will have a negative impact on AMF and, ultimately, soil health. To find out more about soil biology, please refer to the **EcoVineyards BPMG on soil health in Australian vineyards: Part B (biology).**

Species selection

Species selection will likely be the most challenging part of the decision making for your ground cover plan. While this will be driven by where you are, what you want to achieve and what you can manage, it is unlikely there will be one, clear answer to these hierarchy of questions!

It is important, though, to approach this with an attitude of 'get started, and then get better'. In simple terms, this means choosing an approach based on the best available information but expecting to make changes and adapt your thinking as the process moves through the first few seasons. The general experience of other growers is important to consider, namely, that preparation, time, patience, and trial and error are all important. In all these other experiences, though, it is the specifics of your property that are the main factor. Start small and scale up as you gain confidence that the species selection suits your site.

The following section discusses the criteria and some ideas on how to go about choosing the species to be included in your program.

Some considerations when selecting ground species include:

- **insectary mixes to provide habitat for predatory arthropods, insectivorous birds and improve pest and disease management**
- **nematicides as a component in a multispecies mix (given the issue with brassicas not hosting AMF)**
- **nitrogen fixers (assessing nodulation after inoculation with rhizobia bacteria)**
- **cereal crops for organic matter**
- **herbaceous plants for increased AMF activity**
- **using deep-rooted plants (e.g., turnips, chicory) for wet areas, compact soils, and/or hardpans**
- **drought hardy species for warm inland areas (sandy soils)**
- **forage species for sheep grazing**
- **selecting species for saline areas, or areas with high/low pH**
- **plants that grow < 30 cm and may be suitable for the under-vine area.**

Figure 14. Multispecies cover crop, with two types of oats, field peas, radish, grasses (left) and cereal cover crop, Victoria [Photos: Steve Faulkner].

Budget

Preparing a budget for a ground cover plan is an important part of ensuring the program will be correctly implemented. However, whilst some of the input costs are relatively simple to include, for example, seed, fertilisers, tractor time, contractors, etc., other elements of the budgets may be more challenging to calculate.

The economic contribution of improved ground cover management is long-term. Improvements in soil biology may occur quickly, but measuring the impact on vine health may take several seasons to show. Whilst soil nutrition will improve, it is not likely that managers will reduce their inputs until evidence for this is seen. This is also discussed by Fleishman (2021) who indicates that benefits may take many years to be clearly identified.

Whilst case studies in viticulture and other crops (Kremen, 2020) show that the initial establishment costs may be high and take several seasons to appreciate. As Kremen 2020 states: *"...a technique may provide economic benefits as well as the potential for greater resilience to environmental shocks."*

A key part of the cost assessment is to look over a longer time period; evidence of accumulated benefits needs to be calculated, namely, the annual cost of some cover crops compared with a poential one-off establishment cost for perennial species.

In the case of establishing a permanent native vegetation ground cover, the return on investment may take several seasons to be realised but then provides considerable benefits when accumulated cost savings and benefits are calculated.

An example of the cost and benefit of transitioning from annual cereal crops to perennial native grasses

We reviewed the cost of transitioning from an annual cereal cover crop to a multispecies mix of native perennial grasses and forbs.

The cereal cover crop costs approximately $1,282/ha annually to establish and manage.

The combined upfront cost of preparation in year 1 and seed in year 2 to establish native grasses and forbs is approximately $2,444/ha.

Therefore, the grower can break even in year 2. The same growing season the perennial native grasses and forbs are sown (assuming a preparation year), which only need to be sown once and save up to $1,282/ha per year thereafter.

This transition also results in a reduction in the time and costs associated with establishing and managing an annual cover crop (discing, sowing, slashing, herbiciding, etc.).

Moreover, it may be possible to produce up to 10 to 15 times the amount of wallaby grass seed when the plants mature after two growing seasons compared to the original seeding rate (10 kg/ha) and this provides a huge potential advantage when assessing the cumulative benefits of seed production over a five-year period.

The additional income generated could be as high as $59K/ha (or an average of $11,810/ha per year) if transitioning from an existing cover crop.

This is based on the value of native seed saved if harvested for reuse, omission of insecticide as the biocontrol provided by the perennial ground cover is often adequate to ensure pests such as light brown apple moth (LBAM) are kept below economic thresholds, associated ecosystem service benefits relating to soil health (nutrient cycling, water infiltration, organic matter) and a discernible improvement in fruit quality.

If starting on a green field site with adequate preparation, the income generated could be as high as $20 to 30K/ha per year (assuming 100 to 150 kg of seed is produced per hectare at $200/kg or more) once the native perennial grasses are established, with little or no ongoing maintenance costs and the benefit of associated ecosystem services.

This example of a stacked enterprise presents an excellent option for growers including the warm inland wine regions to fully utilise their vineyard area, diversify, spread risk, nourish the soil and generate additional income for the business.

To find out more, please refer to the EcoVineyards ground cover cost and benefit ready reckoner.

Figure 15. Mixing native seed and combining with sawdust prior to putting in the seed box (left) and the Seeding Natives 'blue devil' seeder (right) [Photos: Dan Falkenberg].

Figure 16. The nature of perennial tussock wallaby grasses which grows in clumps with gaps in between (left) [Photos: Dan Falkenberg], and native grass seed harvester [Photo: Mary Retallack].

Figure 17. Wallaby grass recruiting where herbicide application has ceased (left) and wallaby grasses growing in the undervine area, Barossa, South Australia (right) [Photos: Dan Falkenberg].

Nordblom et al. (2021) looked at the financial analysis of different under-vine treatments over two seasons in four districts of South Australia. Their results found that herbicide control of under-vine weeds was more profitable in the dry inland region of the Riverland, but in other regions it was outperformed by other under-vine management practices, including ground covers.

However, Nordblom et al. (2021) did not consider all aspects of improved ground cover performance in their financial assessment, and it was not a long-term assessment. What it does indicate, though, is that ground cover management will impact on the financial performance of a vineyard, and each grower needs to assess this prior to and as part of the monitoring program of their practice change.

When assessing benefits, it is worth considering them along the lines of the four categories of ecosystem services, namely, provisioning services (those that contribute to vineyard costs and returns directly), regulating services (those that contribute to vineyard functions), cultural services (non-material benefits) and supporting services (for example nutrient cycling).

In summary, the main considerations for developing a budget are:

Tangible costs and returns

- input costs that can be easily calculated – ground preparation, seed, fertiliser, equipment, labour
- output costs that can be easily measured, such as improved grape production, reduced herbicide use, changes to nutrient requirements, etc.
- can include physical outputs, such as mulch that can be used in the vineyard or sold (this could also include animal feed harvested from the mid-row), or seed that can be harvested and sold or re-used in other parts of the property; this is especially suited to native seeds
- carbon or biodiversity credits that provide a financial return or can be attributed to other parts of the processing and marketing activity/value chain.

Intangible costs and returns

- time and learning inputs of the vineyard manager/vineyard team
- improved soil biology, improved vineyard resilience
- aesthetic value.

Further information

EcoVineyards ground cover cost and benefit ready reckoner can be used by growers and managers to understand the financial impacts of their ground cover program, including opportunity costs and benefits accumulated over a five-year period.

Wine Australia's ground cover selection tool can assist in decision making based on single traits.

EcoVineyards has a range of resources available, and this includes detailed native plant community species lists for wine regions located in Western Australia, New South Wales, Victoria, and South Australia.

IMPLEMENTATION: PREPARATION, SOWING AND ONGOING MANAGEMENT

The process of implementation flows on from the above sections. As has been stated earlier, the approach of getting started and then making improvements based on the lessons learned is important.

The situation analysis mentioned earlier of this guide is also the starting point for the implementation plan.

Process

Implementing your ground cover management plan is not a simple process of sowing some seed. Whilst a mid-row ground cover is relatively easy to plant and, as it is generally not a crop to be harvested for commercial purposes, the germination, growth, and level of weed infestation is not critical. However, depending on the decisions made in relation to a comprehensive, fully functional ground cover plan, the level of effort to do this successfully will be greater.

Similarly, the benefit of harvesting seed for re-use may be a key driver if an alternative source of income is sought (see the native grasses example above) or in an organic setting, a grower may consider producing botanicals for gin production in the mid-row as a cash crop.

The following section steps through some of the items that will need to be considered when implementing the plan you have developed.

Equipment

The equipment required will depend on the type of program that has been developed.

Most vineyards have access to equipment to control weeds prior to installing a ground cover program, and to prepare a seed bed. Similarly, once the ground cover is established, management is usually achieved with standard equipment, such as slashers/mowers, although the addition of a roller (or 'crimper' – see below section on management) are relatively easy to obtain.

The most specialised equipment will be for seeding of ground covers. If a mid-row commercial crop species will be used, then suitable seeders are widely available, and most properties will already have access to one. These are generally a seed drill type machine with a combination of seeding implements, including discs or tines. These generally do not require heavy tilling (for example, rotary hoeing) of the soil prior to sowing, although mulching of prunings is still required beforehand. Many seeders come with more than one seed box that can be used for different mixes, where some seeds are too small to work in a normal mix, or to add some fertiliser to help with crop establishment.

Native seeds can be much more difficult to sow as they do not 'flow' like many commercial crop seeds. There are commercial service providers in some regions who can assist growers with seeding these crops using a purpose-built seeder that can carry the seeds in a suitable carrier (sand, wood shavings, vermiculite, compost, liquid, or air).

Hydroseeding is another system that can be used for under-vine seeding, but, again, will require more specialised equipment that is often used by a contractor.

For more information on these practices please refer to **Section 3: Native grasses and forbs in vineyards.**

Figure 18. Mixing custom seed blends (left) faba beans in a blend with small seeds, makes seeding difficult and causes jams in the seeder (right) [Photos: Steve Faulkner].

Figure 19. Seed produced from snail medic (left) [Photo: Liz Riley], and legume seed germination (right) [Photo: Steve Faulkner].

Ground preparation

Soil preparation is critical for the establishment of a ground cover that has been designed for the purpose laid out in an overall ground cover plan.

The level of effort in preparing the seeding area will be driven by the choice of ground cover. If the choice is to allow volunteer, endemic species to establish, then managing undesirable or noxious weed species is still required. A crop of introduced species will require the establishment of a clean seed bed to allow for even germination.

If the decision is to establish native species, then the preparation may need to be done over more than one season to extract the weed seeds. Native species tend to germinate slowly and are not particularly strong competitors during the early stages of development. Ensuring weeds are controlled well before planting is important, and this may be required over at least two seasons to get a clean stand. It is also recommended in many situations that a week after sowing the native seed, a herbicide is applied when weed seeds germinate and before the natives have emerged to reduce the weed seed burden.

It may be possible to fortify the herbicide mix with fulvic acid at a rate of one-part fulvic acid to five parts herbicide to increase the efficacy and reduce the herbicide rate by 30% and feed the microbes at the same time (Integrity Soils, 2023).

Figure 20. Seed bed preparation (left) [Photo: Steve Faulkner], and a Duncan vineyards seeder (right) [Photo: Jerome Scarborough].

Seeding

There are a range of seeding methods that can be employed that depend on the type of seed and location of seeding to be implemented. Installation of mid-row crops, with commercial mixed species, can normally be done with standard disc, drill, or tine seeders.

Figure 21. Calibrating a Clemens seeder (left) and in action (right), Mornington Peninsula, Victoria [Photos: Steve Faulkner].

Timing

The decision on when to sow can be split into several difference questions:

- What time of year to sow the specific seed being used? This may be complicated when using multispecies mixes.
- When to sow after ground preparation is complete? Including after weed control programs.
- When to sow in the crop development cycle – should ground covers be established before or after planting, or once vineyards are established?

Figure 22. Seed germination, Yarra Valley, Victoria [Photos: Steve Faulkner].

Hydroseeding

Hydroseeding is the process of mixing seed with water and a 'carrier' of paper, wood fiber, mulch or other biodegradable material that allows for the even distribution of the seed. This mixture is sprayed onto the zone to be established. It is a method often used in situations where seed cannot be spread by conventional means, for example, on roadsides or in mine and quarry remediation. The method may be employed for under vine seeding, or when spreading seed across steep areas that are not accessable using conventional seeding equipment. Hydroseeding has been used in some vineyards to sow seed in the under vine area (Retallack, 2021).

Figure 23. Hydroseeding in the undervine area, August 2021 (left), November 2021 sub-clover growth, Grindstone Vineyard, Wrattonbully, South Australia (right) [Photos: Susie Harris].

For more information, please download the **EcoVineyards case study: Grindstone Vineyard**.

Ground cover management

Any approach to managing the ground cover of your choice will reflect the decisions made above. If you are aiming for biomass to build soil carbon or reduce vineyard temperatures, then decisions need to reflect this. If you want to manage weeds under the vine, then more regular mowing with a side throwing mower may be best. If you are trying to break hardpans using a deep-rooted plant, then less slashing is important.

If you need flowers for beneficial arthropods, then ensuring this occurs before any disturbance (including slashing) is important. If you are establishing native grasses then the use of a sponge wiper may help knock back the weedy species and let the native species grow with reduced competition in spring.

Regular mowing will reduce the diversity of arthropods, as well as plant species, and also reduce the net capture of greenhouse gas equivalents (Wolff et al., 2018). Similarly, don't slash perennial ground covers until after they have set seed (or select low growing species that don't require slashing). Rolling or crimping of the mid-row crop is becoming a more common way to manage the height of ground covers.

Figure 24. Side slashed cover crop resulting in an underwhelming undervine mulch (left) and cover crop rolled with a Berti mulcher turned off (right), Victoria [Photos: Steve Faulkner].

Figure 25. Rolling with a Berti mulcher that is turned off (left) and the resulting rolled cover crop in the midrow (right), Victoria [Photos: Steve Faulkner].

The choice to mow, roll or 'crimp' a ground cover will be driven by these same choices and the availability of equipment. There may be a trade-off between these and other vineyard activities, but this is why having a clear hierarchy of reasons for the ground cover is important so that these decisions are consistent with the overall outcomes being targeted.

Strategies can also extend beyond just the frequency of mowing, such as the mowing of alternate rows to keep growth in check but having a consistent amount of flowering or crop height available to meet other requirements. The cutting height can also have a major impact on the amount of carbon stored, rooting depth, and overall biomass production.

Slashing and grazing

As a rule, 'graze half and leave half' and always leave a minimum of 15 cm of vegetative growth (or the height of a soft drink can).

The importance of this concept can be demonstrated via the work of Crider (1955) who conducted a series of experiments on plant defoliation on cool and warm season grasses.

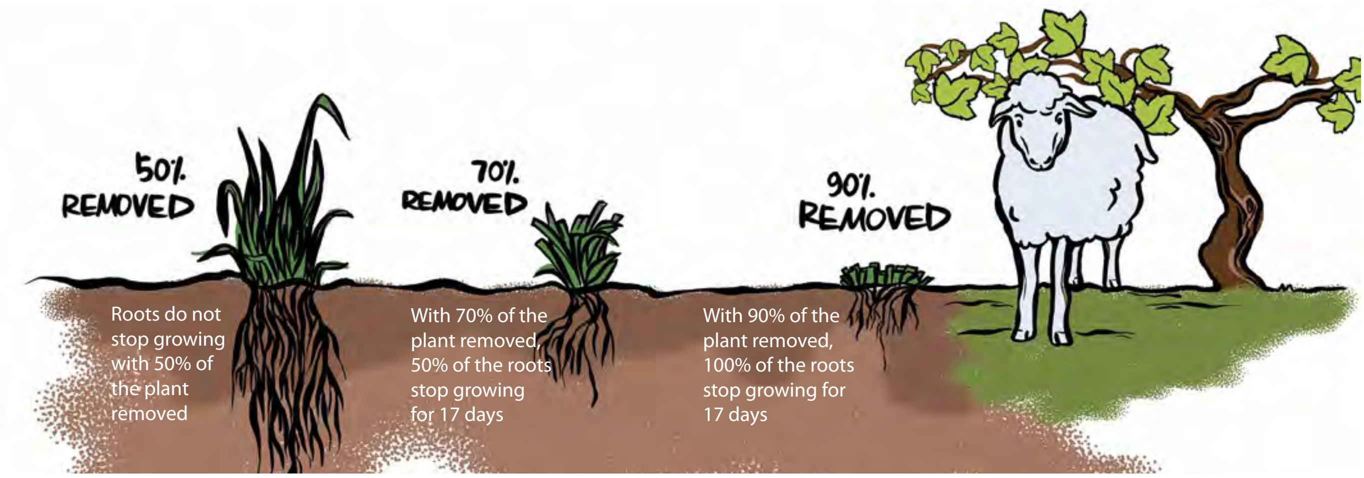


Figure 26. The effect of defoliation on root recovery and subsequent growth.

Table 3. Defoliation effects on roots (Crider, 1955)

Percentage of leaf volume removed	Percent root growth ceased
10%	0%
20%	0%
30%	0%
40%	0%
50%	2 to 4%
60%	50%
70%	78%
80%	100%
90%	100%

In one experiment with a single harvest, plants were trimmed at 10% increments, 10% trimmed and 90%, left, 20% clipped and 80%, left and so on. The results were stunning. At up to 40% defoliation (leaving 60% behind), 0% of roots ceased to grow.

As soon as more than 50% of the plant material was removed, this level and higher dramatically increased the percentage of roots that stopped growing. When 80% of the forage was removed, 100% of the roots stopped growing. It took anywhere from 6 to 18 days, with an average of 11 days, for the roots to begin re-growing and new top growth (leaves) to appear. If we return to a paddock before the plant begins to re-grow, then the plant doesn't have an opportunity to regrow, or recharge its stored carbohydrates (energy) reserves (Schriefer, 2021).

Controlling weedy species

Weed control is an important part of managing the ground cover system you have chosen. As we are not looking (in most cases) to harvest the ground cover, then some weeds can be tolerated. If a system of managing volunteer species is being used, then the threshold for weed control will be very high. Managing undesirable species, or noxious weeds, is important, and may be required by local laws/regulations, so determining the requirements of your system is important.

Figure 27. TMC Cancella under-vine mower attached to a self-fabricated frame on the back of the mid-row slash, Eden Valley, South Australia [Photos: Dan Falkenberg].

Weed control prior to and early in the development of native species is very important. The use of selective herbicides, as well as weed wipers as opposed to spray units, may be preferred.

The level of weed control and product selection will be determined by the type of system being used but should reflect the overall strategy being developed for the ground cover. If you are growing grasses conventionally, then you may have access to broad leaf selective herbicides that are registered for use in vineyards.

Other considerations

Vines require annual pruning, and managing the canes pruned from the vines without disrupting the ground cover can be a challenge.

It is possible that mowing the ground cover down will be necessary before pruning if the ground cover consists of tall species. But it also needs to be remembered that the canes are organic material and are best used in the vineyard to increase soil organic matter and carbon. Removing and burning canes is not the preferred method for managing this resource. Mulching of the cane material will impact the ground cover, but if this is timed correctly, it can be dealt with in the normal growth cycle of the ground cover.

There may be a need to terminate the ground cover crop, for example, to manage frost or other vineyard activities. Whilst this should only be necessary on annual crops, or to control weedy species within a perennial crop, the use of a registered herbicide is the most common option. However, herbicides should only be used when other options, such as short mowing or light tilling, are not better alternatives. Always feed the soil biology after a herbicide application to help their populations rebound.

For more information on supporting soil biology please refer to the **EcoVineyards best practice management guide on soil health in Australian vineyards: Part B (biology).**

MONITORING: WHAT HAS BEEN ACHIEVED AND HOW TO CONTINUE TO IMPROVE?

As is made clear in the above sections, there are many variables to consider in assessing the ground cover management of the vineyard. Whilst some growers will be happy to judge the performance on aesthetics and environmental principles alone, it is still important to understand the impacts that are being achieved.

It is advisable that growers and vineyard managers develop a small set of criteria from which they can judge the performance of a ground cover plan. These will be determined largely by decisions on which the program was made. If access, drainage, or breaking hardpans was the aim, this can be measured by visual observations and perhaps some digging.

Improved management of pests, diseases, and weeds, or improved efficiency of nutrition usage, may not be easily measured in one season, but observations over more than one year should give a good indication of changes occurring. Even more difficult to assess in a short period of time are impacts on grape quality and/or quantity, and if this results in better returns to the grower. Seasonal variations in not only grape parameters, but also pricing, will potentially mask some of these impacts.

Setting aside areas where changes are not implemented (i.e. a control area) or conducting a strip trial (in the mid-row of a single row), will improve the ability of the grower to assess changes observed.

Direct observations of the ground cover should also be included, which may point to the better species mixes that can be developed for each site. `

Other assessment options include:

- Measuring the fresh weight of the crop
- Counts of richness (diversity) and abundance (number) of arthropods
- Direct measurements of ground cover species.

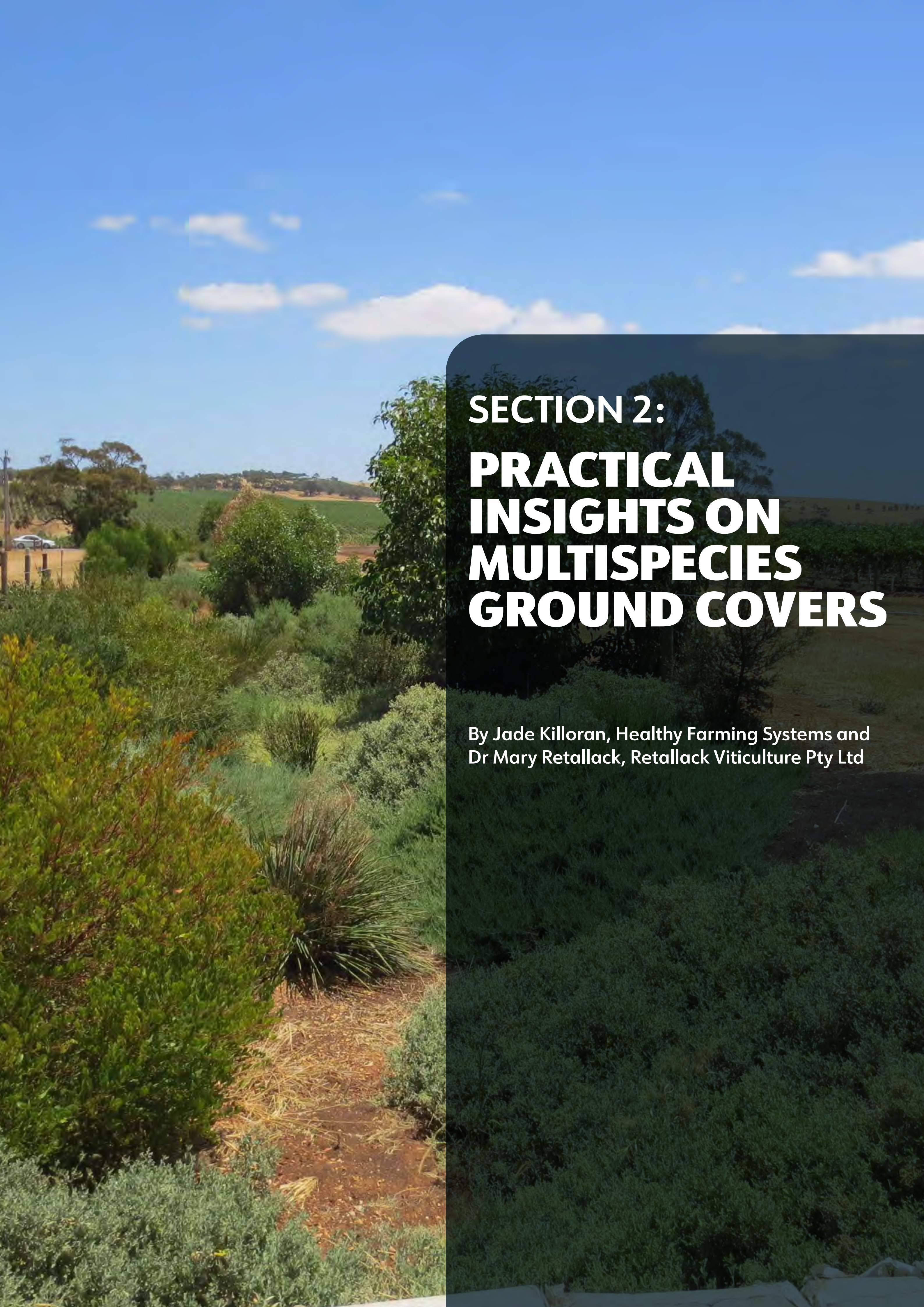
An important measurement to take is how things are before changes to the ground cover program. This can include species richness, soil biology, soil nutrition, and other physical and chemical properties. An important consideration if carbon capture is one of the important drivers is to take soil carbon measurements as a baseline. These measurements will be different to the results from the normal monitoring of soil properties undertaken by most managers.

Further information

- EcoVineyards: Knowledge hub
- Lower Blackwood LCDC: Data Collection to Monitor Pasture Health and Productivity
- University of Adelaide: Soil ecology research group.
- Wine Australia: Cover crop factsheets
- Wine Australia: Cover cropping decision support tool

Long term studies: Long term studies will continue to provide data on the benefits to soil and vine health, as well as environmental benefits. These include projects such as:

- Germany: Jena Experiment
- Ireland: Teagasc
- UK: Rothamsted



SECTION 2:

PRACTICAL INSIGHTS ON MULTISPECIES GROUND COVERS

By Jade Killoran, Healthy Farming Systems and
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WHAT ARE MULTISPECIES GROUND COVERS?

Multispecies ground covers are diverse seed blends that are grown to improve vineyard environmental and economic outcomes. A multispecies mix should be functionally diverse for maximum benefit and contain at least one plant species from each of the four main plant groups (legumes, grasses, tall and short forbs/broad leaves). Usually, a 6 to 12 species blend of annual plants is sown first to increase diversity and aid a transition to perennial species (where applicable), which can be achieved over two to five years.

The benefits of ground covers for vineyards

As previously discussed, a 'bare earth' policy leads to higher weed pressure, lower soil carbon levels, soil compaction, reduced water infiltration and plant-available nutrients, and a loss of ecosystem services linked to biodiversity. While a monoculture (sowing of a single species) is preferable to bare earth, these low diversity systems are vulnerable to stress events, such as drought, frosts, pests, and weeds, requiring ongoing intervention by the viticulturist.

Figure 28. Bare earth creates a dead zone devoid of soil biology [Photo: Mary Retallack].

Bare earth puts microbes on a starvation diet, and often you can see the mid-row has become a dead zone where last year's canes have not broken down due to a lack of soil biology.

In comparison to conventional growing systems, natural environments are highly biodiverse and resilient. Production systems can emulate natural environments by changing from a bare earth or monoculture system to a multispecies ground cover.

Multispecies ground covers can be a relatively easy way for growers to integrate many beneficial agricultural principles with one practice change.

These include:

- increasing plant diversity
- increasing ground cover
- minimising soil disturbance
- always maintaining living roots in the ground
- livestock integration (if possible).

These changes have a positive effect on biodiversity, natural capital, and ecosystem function, which are strongly linked to the profitability, resilience, and regenerative capacity of the growing system. The driver of the benefits is increased plant diversity, and the positive effect this has on the soil biological population.

By maximising plant cover you can fully utilise nature's solar panels to drive the liquid carbon pathway with exponential benefits. A bare earth, or low diversity system, has living roots in the soil for a limited time each year. In comparison, the aim of a multispecies ground cover is to have diverse living roots in the soil all year round.

These living roots support soil biology, such as bacteria and fungi, by transferring 'liquid carbon' sugar-rich exudates from photosynthesis into the soil surrounding the root system (Jones 2015).

In return for these exudates, soil biology, particularly fungi, provide moisture and nutrients back to plants. When the cycle is functioning well, soil biology source, cycle and transport many nutrients that plants require for growth. Without this plant-biology interaction, many minerals and trace elements are not plant-available (Jones, 2015).

Recent studies have shown that the availability of key nutrients, such as nitrogen and phosphorus, as well as carbon stocks, can be improved under multispecies ground covers (Cong et al., 2014). In addition, soil aggregation, soil structure, and moisture infiltration and retention can also improve under multispecies ground covers (Blanco-Canqui et al., 2012).

From an 'above ground' perspective, a multispecies ground cover mix will occupy multiple seasonal 'niches' and will commonly produce more biomass than comparable monocultures (Farrell et al. 2021).

Diversity reduces the risk of crop failure and improves the amount and season length of ground cover, helping to keep topsoil temperatures more stable, preventing wind, water, and sun damage to the soil surface, reducing topsoil loss, and providing competition for weeds.

The adoption of multispecies ground covers allows a grower to pivot to a more biodiverse system with improved soil health, plant health, and resilience to stress events. This type of system requires less intervention and reduced reliance on costly inputs, such as chemicals and fertiliser. These systems often show an improvement in profitability and sustainability. In addition, there is the opportunity to integrate livestock to increase nutrient availability to plants (through animal waste) and offset multispecies costs by livestock production and business diversification, which spreads financial risk and improves property and business resilience.

Figure 29. Ground covers need moisture to thrive as demonstrated by this pollinator blend growing with good growth where there is an irrigation leak compared to growth via rainfall only in a dry season [Photos: Liz Riley].

This holistic systems approach is becoming more valued by the consumer, supply chain, and other stakeholders, with a greater demand for enhanced environmental stewardship and sustainable products being shown. Properties adopting regenerative practices, such as multispecies ground covers, can benefit their businesses in a myriad of ways, accumulate carbon and biodiversity credits, and become a part of the climate change solution.

MULTISPECIES GROUND COVER SELECTION

European varieties most likely to be suited to Australian vineyards

The best approach when deciding what to sow in a multispecies mix is to determine what species thrive in a vineyard or local area. Identification of regionally specific plant species can be assisted by an agronomist.

Choosing one or two species from the grass (Poaceae), legume (Fabaceae) and tall and short broad leaf families (Brassicaceae, Plantaginaceae, Asteraceae, Linaceae, Polygonaceae etc). will ensure appropriate functional diversity.

Prior on-farm projects conducted by Healthy Farming Systems in the livestock and cropping sectors have found the following common European species suit the climatic conditions of southern Australia:

Annual species for autumn sowing:

- grasses (Poaceae family) winter cereals, such as oat, ryecorn, triticale, wheat and ryegrass
- legumes (Fabaceae family) vetch, pea, faba bean, clover, and medic
- tall and short broad leaves from the Brassicaceae (tillage radish, fodder rape, turnip) and Linaceae (linseed) families.

Annual species for summer sowing (if appropriate):

- grasses (Poaceae family), such as millet or sorghum
- legumes (Fabaceae family), such as summer active clover, vetch, or tropical legumes

  tropical legumes, such as cowpea, lablab, and mung bean, may not perform optimally in cooler southern conditions.
- tall and short broad leaves, such as buckwheat, sunflower, linseed, tillage radish, and fodder rape.

These summer-active species are best used in the mid-row first to assess their possible effects on vine yield. Any perennial plants considered for the under-vine area should also be chosen for their prostrate growth habit (ideally < 30 cm).

Figure 30. Summer multispecies mix, Gippsland, Victoria [Photo: Jade Killoran].

Figure 31. SARDI Persian clover cover crop (left) [Photo: Liz Riley] and radish (right), Yarra Valley, Victoria [Photo: Steve Faulkner].

Figure 32. Faba bean cover crop (left) and rhizobia nodulation on roots (right), Yarra Valley, Victoria [Photos: Steve Faulkner].

Figure 33. A conventional pasture (left), compared to an annual summer multispecies mix (right), western districts, Victoria [Photos: Jade Killoran].

Fast-growing annual species are a lower cost, quicker establishing option than perennial species. They will tolerate poorer growing conditions and their rapid establishment helps to smother weeds and resist disease and insect attack.

Annual mixes 'prime' the soil by improving soil health and help give the operation flexibility in dealing with any constraints or issues that may arise. Once soil health has been improved using annual species, perennial multispecies can be sown if desired.

Caution when grazing

If grazing is planned, some species mentioned in this article, such as buckwheat, clovers, linseed, and sorghum, can have negative effects on animal health and consultation with a local agronomist pre-sowing or grazing is recommended if these species are included in mixes.

Table 4. Cool and warm season multispecies ground cover options

Cool season grass Family: Poaceae	Cool season broad leaf (various)	Cool season legume Family: Fabaceae
barley	linseed	vetch
wheat	plantain (perennial)	faba bean
oats	tillage radish	field pea
ryecorn (cereal rye)	turnip	annual clovers
triticale	fodder rape	perennial clovers
ryegrass (annual/perennial)	canola	lucerne (perennial)

Warm season grass Family: Poaceae	Warm season broad leaf (various)
millet	buckwheat
sorghum	sunflower
corn	chicory (annual/perennial)
sudan grass	
teff (northern areas)	

Table 5. Autumn, spring, and summer sowing times for multispecies ground covers and functional group by family

Autumn sowing	Spring sowing	Summer sowing
Family: Poaceae	**Family: Poaceae**	**Family: Poaceae**
barley	barley	millet
wheat	wheat	sorghum
oats	oats	corn
ryecorn (cereal rye)	ryecorn (cereal rye)	sudan grass
triticale	triticale	teff (northern areas)
annual ryegrass	annual ryegrass	
Family: Fabaceae	**Family: Fabaceae**	**Family: Fabaceae**
vetch	vetch	red clover
faba bean	peas	**Family: Linaceae**
peas	red clover	linseed
annual clovers		**Family: Polygonaceae**
perennial clovers		buckwheat
Broad leaf (various)	**Broad leaf (various)**	**Family: Asteraceae**
linseed	linseed	sunflower
tillage radish	tillage radish	chicory (annual/perennial)
turnip	turnip	**Family: Brassicaceae**
fodder rape	fodder rape	tillage radish
canola	canola	turnip
mustard	mustard	fodder rape

The species recommended in this selector have been identified through trial and project work undertaken by Jade Killoran, Healthy Farming Systems, in livestock systems in southern and central Victoria from 2019 to 2024.

Figure 34. A mid-row autumn multispecies mix colonising the under-vine area (left), autumn multispecies mix, western districts, Victoria (right) [Photo: Jade Killoran].

Perennial species

Perennial grasses, legumes, and herbs can be used to populate the mid-row once soil conditions are considered appropriate, if perennials are suitable for use in the vineyard. Examples include ryegrass, cocksfoot, and fescue (Poaceae), as well as perennial clovers and medics (Fabaceae), and chicory and plantain (Asteraceae and Plantaginaceae).

Phalaris is a deep-rooted grass and may compete with vines in organically grown vineyards where the grasses cannot be chemically managed. It can also be used to grow bulk and reduce vine vigour where needed. Cocksfoot and fescue are also deep-rooted perennial grasses.

C_3 and C_4 plants

Cool and warm season plants:

- C_3 plants are adapted to cool season establishment and growth (most active in autumn to spring) and have greater tolerance to frost and cold conditions than C_4 plants; most plants on earth are C_3 plants.
- C_4 plants have evolved under hot, dry conditions, and their photosynthesis cycle has evolved in a different way to minimise moisture and energy loss from the plant.

Examples of C_4 plants that may be used as multispecies ground covers in Australia are found mainly in the Poaceae family (corn, millet, sorghum, native kangaroo grass, and windmill grass) but also lucerne and some amaranth species. Annual and perennial C_3 species are more likely to suit the vine activity cycle by confining most of their growth to the autumn, winter, and early spring.

Addressing specific constraints

If there are specific constraints or issues that you would like to address, this list may help you to further refine the makeup of the multispecies mix.

- **Biomass production:** Focus on the grass family, particularly cereals.
- **Compaction alleviation**: Tap-rooted plant species, such as tillage radish grow deep tap roots and can help break up soil at depth.
- **Wet ground:** Autumn-sown plants that tolerate waterlogging, such as ryegrass, clover, and plantain, followed by, if feasible for the vines, summer multispecies with a high ratio of tap-rooted and deep-rooted species, such as tillage radish and sunflowers, to deplete the soil moisture profile.

  Broadleaved species including plantain may harbour LBAM.
- **Nitrogen fixation:** Legumes inoculated with the correct rhizobia strain will fix nitrogen effectively. If broad leaves and legumes form a significant portion of the mix their lower carbon residue also helps accelerate the decomposition and nutrient cycling of the multispecies biomass.
- **Insectary/pollinator species:** Flowering species are already common in multispecies mixes. Legumes, brassicas, chicory, plantain, sunflowers, phacelia, alyssum, and buckwheat are all attractive to pollinators.

  It has also been reported that the presence and longevity of LBAM may be extended in the presence of buckwheat and its fecundity (reproductive capacity) could be enhanced by the availability of nectar plants such as *Borago officinalis*, borage; *Trifolium repens*, white clover; and *Brassica juncea*, brown mustard.

Figure 35. Predatory arthropods like this hover fly are attracted to flowers that offer nectar, pollen, and a source of alternative prey like *Ranunculus lappaceus,* Australian buttercup, Belair, South Australia (left) [Photo: Mary Retallack] and a commercial pollinator blend, Hunter Valley, New South Wales (right) [Liz Riley].

- **Drought-hardy species:** Tap-rooted and deep-rooted plants, such as tillage radish, sunflowers, and herbs.
- **Saline areas:** Some European and native species are tolerant to saline areas and waterlogging. The Victorian and West Australian government have excellent resources available on this topic including:
  - Agriculture Victoria: Salinity indicator plants – A guide to spotting soil salting
  - DPIRD, WA: Salinity tolerance of plants for agriculture and revegetation in Western Australia

  Some potentially useful species are ryegrass, balansa and strawberry clover, phalaris, bucks horn plantain, medics, pigface, Australian salt grass and various native salt bush species.
- **Weedy areas:** Competition from a heavily sown and diverse multispecies mix can help fill weed niches with competitive species, although if the area contains more than 50% of a particular weed, then chemical or cultivation strategies should be considered prior to sowing the multispecies as post-sowing chemical control will be limited by the diversity of the mix.
- **Nematicides:** If the pathogenic nematode infestation is considered severe, sowing high rates of brassicas in the multispecies mix, or a monocultural brassica crop, can help reduce the impact of nematodes in a process called biofumigation.

  Brassicas contain glucosinolates that break down to form isothiocyanate gas, which controls the nematode population. Brassicas, such as mustard, fodder rape, or tillage radish, can be grown in the mid-row to 25% flowering, then mulched and incorporated into soil, either in the mid-row or side-thrown to the under-vine area. The biomass should be rolled or irrigated afterwards to seal the soil and retain the gases.

The presence of damaging nematode populations can be an indicator of poor soil biodiversity and health. Multispecies mixes will help support a broader range of predatory soil biota to produce pest suppressive soils.

Figure 36. Root galls due to root-knot nematode infestation, Blewitt Springs, South Australia [Photos: Mary Retallack].

APPLICATION IN THE VINEYARD

In general, conventional growing systems, including many vineyard practices, have gradually reduced the diversity and complexity of the production system, and have replaced many natural functions with interventions, such as synthetic fertiliser, chemicals, or mechanical tillage. A return to regenerative agriculture practices, including the use of multispecies ground covers could help regenerate soils, ecosystems, and vineyard businesses.

Benefits of a living soil

As mentioned previously, the beneficial plant-soil biology interaction is enhanced by species diversity. Results from the Jena biodiversity experiment in Germany and recent Australian research conducted across the agricultural sector have shown improvements in plant biomass, topsoil cover and temperature, soil structure, microbial biomass, carbon levels, nutrient cycling, moisture infiltration, pest, weed, drought resilience, and grow profitability and sustainability.

Australian researchers are demonstrating that these positive benefits can be achieved at the property level, with Dr Mary Retallack, Dr Joseph Marks, Dr Thomas Lines, Professor Tim Cavagnaro and Chris Penfold contributing significantly to this area of vineyard research in Australia.

Figure 37. Aggregated soil structure showing the presence of glomalin, causing soil to cling to plant roots, central Victoria [Photo: Jade Killoran].

Soil food web

A further benefit strongly related to vineyards in adopting multispecies ground covers is described by Dr Elaine Ingham, creator of the Soil Food Web, who suggests that perennial woody crops grow best when soil has a higher proportion of fungi-to-bacteria.

A ratio of about 1.6 to 2.0:1 for grapevines (Pearce, 2020) along with health populations of all functional soil biology groups is recommended.

Mycorrhizal fungi are a significant part of the 'bridge' between minerals and plants, forming a symbiotic beneficial relationship with over 90% of plant species. Plants host the mycorrhizal fungi (MF), which live in and on the plant roots, and in return for carbon exudates, extend very fine hyphal filaments through the soil, significantly improving access to moisture and nutrients.

AMF produce a substance called glomalin that can help improve soil aggregation, soil carbon storage, and enhance growth under abiotic stress (Irving et al., 2021). The carbon polymers formed by these fungal networks also improve soil structure, porosity, cation exchange capacity, and plant growth (Jones, 2018b), and they also help to initiate plant response to pests and diseases, and reduce the effect of salinity and heavy metal toxicity.

Soil fungal populations are adversely and rapidly affected by the removal of host plants from the system, cultivation, and the use of chemicals and synthetic fertilisers. A traditional vineyard system with fallow mid-row and under-vine areas will most likely have a bacterially dominant soil. Adopting multispecies ground covers can create a fungal-dominated soil for optimal vine health and yield while also helping to reduce the cultivation, chemical, and fertiliser use that is so detrimental to fungal survival.

Figure 38. A multispecies cover crop planted up to the butt of the vine, Yarra Valley, Victoria [Photo: Steve Faulkner].

Enhancing biodiversity

Biodiversity improvements can be achieved by creating three biodiversity action zones in and around the vineyard:

1. **Diversifying vegetation in the area surrounding the vineyard:** Using native species in tree and shrub shelterbelts and sowing native grass and broad leaf ground cover mixes in undisturbed areas will create a zone of biodiversity that is extremely beneficial to the vineyard.

2. **Sowing the mid-row:** A functionally diverse multispecies mix can be used in the mid-row. If the row has not been sown often before, and is weedy with poor soil condition, annual aggressively growing European multispecies mixes could be used. A greater diversity of species can be used in the mid-row as there is the opportunity to use taller species, such as cereals, faba beans and brassicas, as well as shorter species, such as ryegrass, clovers, medics, and linseed that act as understorey species in these mixes.

   Mid-row vegetation can significantly reduce topsoil temperature (Leask, 2020) and can also be used to provide nutrients via slashing/mulching into the under-vine area. Growers commonly use a legume/cereal mix in the mid-row if side throwing into the under-vine area is planned. A legume-rich mid-row could provide significant amounts of nitrogen to vines (Penfold et al. 2018). If desired, these multispecies mixes could be used to improve soil condition before a European or native perennial multispecies mix is sown, if appropriate for the vineyard.

Figure 39. Biodiverse landscapes support resilient production systems (left) [Photo: Mary Retallack] and an annual cover crop planted every second row, Yarra Valley, Victoria [Photo: Steve Faulkner].

3. **Sowing the under-vine:** The University of Adelaide has conducted several studies in South Australia examining plant species that can be sown in the under-vine area. At four sites in South Australia, annual self-regenerating legume and grass mixes, specifically ryegrass and clover or ryegrass and medic mixes achieved yields and financial gross margins equivalent to or greater than the herbicide control (Penfold, 2018).

   These European annual mixes were found to be the most cost effective to establish (less than $200/ha for seed) and provided the highest gross margins when compared to perennial grasses, native grasses, straw mulch, and herbicide control (Penfold, 2018). The studies observed that in comparison to annual self-regenerating ryegrass and legume mixes, perennial grasses, such as fescue, wallaby grass, and weeping grass, may suppress yield during establishment due to moisture uptake, especially if summer rainfall or irrigation lengthen their growth period (Marks et al., 2022; Penfold, 2018).

Overall, the research suggested that in Mediterranean-type climates, European short maturity annual winter active grasses and legumes, such as annual ryegrass, clover, and medics, sown in the under-vine area were the most suitable option.

These species provide numerous benefits while actively growing, and then naturally senesce in the spring as the vines are becoming active. This alleviates the risk of moisture and nutrient competition, abolishes the need for termination and provides a mulch over the summer before the species self-regenerate in the following autumn.

Figure 40. Pigface sown in the undervine area, Kuitpo, South Australia (left) [Photo: Jess Hardy] and ryegrass and medic undervine ground cover, Nuriootpa, South Australia [Photo: Chris Penfold].

Transition to native species in the mid-row and under-vine

As demonstrated in previous Australian vineyard studies, European mixes are well suited to vineyards and can provide a viable alternative to fallow mid-row and under-vine areas.

However, once soil health is considered optimal, there is an opportunity to consider sowing carefully selected perennial multispecies mixes in the mid-row, which could include native species. While relatively scarce and expensive compared to European perennial species, native species provide significant benefits to the system as they are less fertiliser dependent than introduced species and have co-evolved with native beneficial insects and local climatic and soil conditions.

The National EcoVineyards Program has pioneered the use of a wide range of native species in vineyards. Case studies of the vineyards that have established insectary plantings or shelterbelts around the vineyard, or insectary plants, native grasses and forbs within the vineyard, can be accessed on the **EcoVineyards website**.

The ratio of annuals to perennials, where they are sown in the vineyard, and the potential transition from European multispecies ground covers to native ground covers must be individually determined by each vineyard to suit the climatic conditions and goals of the vineyard while remaining economically viable.

Establishing multispecies in the vineyard

Sowing timing and considerations

In southern Australian 'high rainfall zones', where rainfall exceeds 700 mm per year, autumn mixes can be dry sown in March to take advantage of the first autumn rain. The risk of a failed autumn break is usually low, and 'sowing dry' means that the multispecies has the maximum amount of time to emerge and grow before conditions become cold and wet, limiting growth. If judged appropriate for the vineyard, spring and summer sown multispecies can be an option for these vineyards as the extra moisture available in these regions makes yield impacts less likely.

In medium to low rainfall zones, it is often best to sow after the autumn break, from April to the end of May, depending on moisture. This is to ensure plants establish well and don't become moisture stressed. Spring and summer sowings are very opportunistic in these regions.

If moisture stress becomes apparent at any time, the multispecies mix could be chemically terminated, mown, grazed, or roller-crimped to control growth and alleviate moisture demand.

Getting Started

1. **Have a goal – a clear goal is essential**

2. **Set a realistic budget and start small to manage risk**

Sowing small areas in the first year will help manage seasonal risk and allows effective benchmarking to normal practices on-property without creating complications for the business.

3. **Prepare the vineyard properly – ground preparation is crucial**

Firstly, when prepping the vineyard, check whether there are obvious issues, e.g. a shallow hard pan, very low pH, excessive weed burden, etc. Be prepared to address issues before sowing.

Figure 41. Tines (preferably offset) such as the Yeoman's plough can be used to open but not turn over the soil and break up hard pans prior to seed bed preparation [Photo: Steve Faulkner].

Ground preparation revolves around reducing competition: Controlling existing plant species at sowing is the biggest determinant of success. If the vineyard is in a ground cover phase or has a weed burden, existing plants will almost certainly be an issue. Hard grazing or mowing, and then direct drilling without herbicide (sowing 'green') is rarely successful on its own.

Figure 42. Paddock preparation showing no herbicide used pre-sowing on the left and the use of herbicide on the right [Photo: Jade Killoran].

Some level of cultivation or chemical application pre-sowing or at sowing is usually necessary, at least for the first few sowings. While in the short-term chemical use or cultivation will negatively impact soil biology, the added diversity will enhance the system and help biology recover and eventually thrive. The risk of a failed sowing through inadequate preparation outweighs short-term, transient damage to soil biology. Ground preparation is crucial.

If weedicides are used, it is possible to apply fulvic acid to reduce the chemical rate required, increase efficacy and feed the microbes so they rebound more quickly (Integrity Soils, 2023).

A low tillage sowing option can be a disc drill coupled with herbicide use. This approach can often reduce disturbance of the weed seed bank, resulting in less weed emergence and soil disturbance, but herbicides will impact soil biology. As a second line of defence, if chemical use is allowed, and there is a dominant weed species, the multispecies mix can be adjusted to suit to give chemical options post-sowing.

If cultivation is considered necessary or more desirable than herbicide use, there are various machines that have been designed to fit in the mid row, such as a power harrow. These machines can create tilth and a workable seed bed if the soil is compacted, and can turn existing biomass into the soil, reducing competition for sown species.

For all vineyards, sowing in a timely fashion with high rates of fit-for-purpose species will help ensure success. For organic vineyards, sowing annual multispecies ground covers each season until weeds are controlled will be the best approach. Very shallow cultivation of weeds prior to sowing the multispecies mixes each year may provide additional control. Livestock may also be used to control problem weeds post-sowing if they are palatable.


Figure 43. A rotary harrow fitted with a seed box (left) [Photo: Steve Faulkner], and power harrow without a seed box [Photo: Weekly Times].

4. Buy bare seed, consider inoculating legumes and applying biological liquids to the seed pre-sowing

Buying bare seed ensures that there are no chemical coatings applied to the seed that may negatively impact soil biology. Seed companies or retailers should provide seed coating information if requested.

Inoculating legumes with the correct strain of rhizobia bacteria within 24 hours prior to sowing often improves nitrogen fixation efficiency, especially if the legume has not been sown in the paddock within the last two to three years.

Rhizobia are a group of soil bacteria that colonise plant root nodules and can greatly improve nitrogen fixing potential.

Inoculation after sowing the legume is very chancy, so seed should be inoculated before sowing. Ensuring that soil molybdenum, zinc, boron, and phosphorus levels are appropriate can also enhance nitrogen fixation. A seed coat using a worm juice, fish/seaweed solution or compost extract can also help to support bacterial and fungal populations (Masters, 2019) and can, consequently, stimulate the germination of seedlings.

Figure 44. Vetch nodulation [Photo: Jade Killoran].

5. Keep an eye on the numbers – benchmark the multispecies

Establishing a baseline for soil health and production before sowing the multispecies and maintaining a control section to benchmark the multispecies against is crucial.

Figure 45. EcoVineyards soil health indicators for Australian vineyards (booklet and posters)

For more information please refer to the Soil health indicators for Australian vineyards and their assessment.

Ecosystem services can also be assessed and the return on investment monitored by assessing yield (vines and multispecies) quality, animal production (if livestock are grazing the vineyard) or input reductions.

Vineyard demonstration of a multispecies cover crop in a young vineyard

A multispecies ground cover in the mid-row of an establishing vineyard was demonstrated in Victoria with the following results:

- no vigour penalty
- no disease increase versus traditional pasture
- less need to mow with improved cover and reduced weeds
- beneficials attracted by multispecies that provided food (nectar/pollen) and habitat
- improved score on visual soil assessment/penetrometer
- aesthetic improvement resulting in greater interest in the business.

Increasing biodiversity in and around the vineyard can provide other opportunities to value add or diversify the vineyard business, and could have further positive effects on the economic, environmental, aesthetic, and marketing outcomes of the vineyard.

Figure 46. Young vines with a mid-row annual summer multispecies ground cover, western districts, Victoria [Photo: Jade Killoran].

Controlling biomass in the vineyard

Mechanical methods

Mechanical biomass control options:

- slashing/mowing and side throwing – which can be beneficial from a vine nutrition perspective
- roller-crimping, which terminates the biomass into a flattened mulch that can be beneficial from a ground cover protection perspective but can be difficult to achieve total termination without herbicide.

However, both options increase labour and fuel use, which can be the biggest contributor to greenhouse gas emissions in the vineyard business.

Livestock management

Livestock can control biomass and add natural fertiliser to the system. Animals, such as sheep, chickens, and guinea fowl, can be moved around the vineyard as needed, particularly between harvest and bud burst, when they are not likely to damage vines.

Sheep will remove suckers as well as debris, while chickens and guinea fowl may be potentially less damaging to vines and able to manage mid and under-vine biomass and pests. Livestock potentially reduce labour, cost, and GHG emissions while diversifying the business. Livestock grazing multispecies ground covers benefit from species diversity and a more balanced diet, which can lead to excellent production outcomes, feed conversion efficiency, fertility, and overall stock health. Stock can be owned or agisted as needed.

Livestock grazing management would ideally focus on short duration, high intensity managed grazing, first popularised by Allan Savory. This type of grazing involves using high stocking rates of the chosen livestock in small areas and moving them regularly every three days to fresh areas while there is still 100% ground cover and several inches of plant residue remaining.


Figure 47. Chickens in the Wayfinder Vineyard scavenge in the mid-row for weevils, Margaret River, Western Australia (left) and sheep can be used to graze vegetation in the vineyard under controlled conditions, Torchbearer Vineyard, Tasmania (right) [Photos: Mary Retallack].

This is usually achieved by using temporary electric fences to divide large areas into smaller 'cells'. Each area should then be rested for a minimum of 30, but ideally 60 to 100 days. This type of management aims to avoid soil and plant damage related to overgrazing, pugging, and selective grazing while improving stock health and production.

A case study at Cumulus Vineyards (AWRI, 2016) details savings and profits made by adding agisted sheep to the vineyard. Richard Leask's Nuffield report also sets out the advantages of regenerative management, including managed grazing in vineyards, stating that he observed the benefits of this intensive rotational grazing system across several different management systems with obvious benefits to soil health (Leask 2020).

Diversifying the business with niche products and marketing

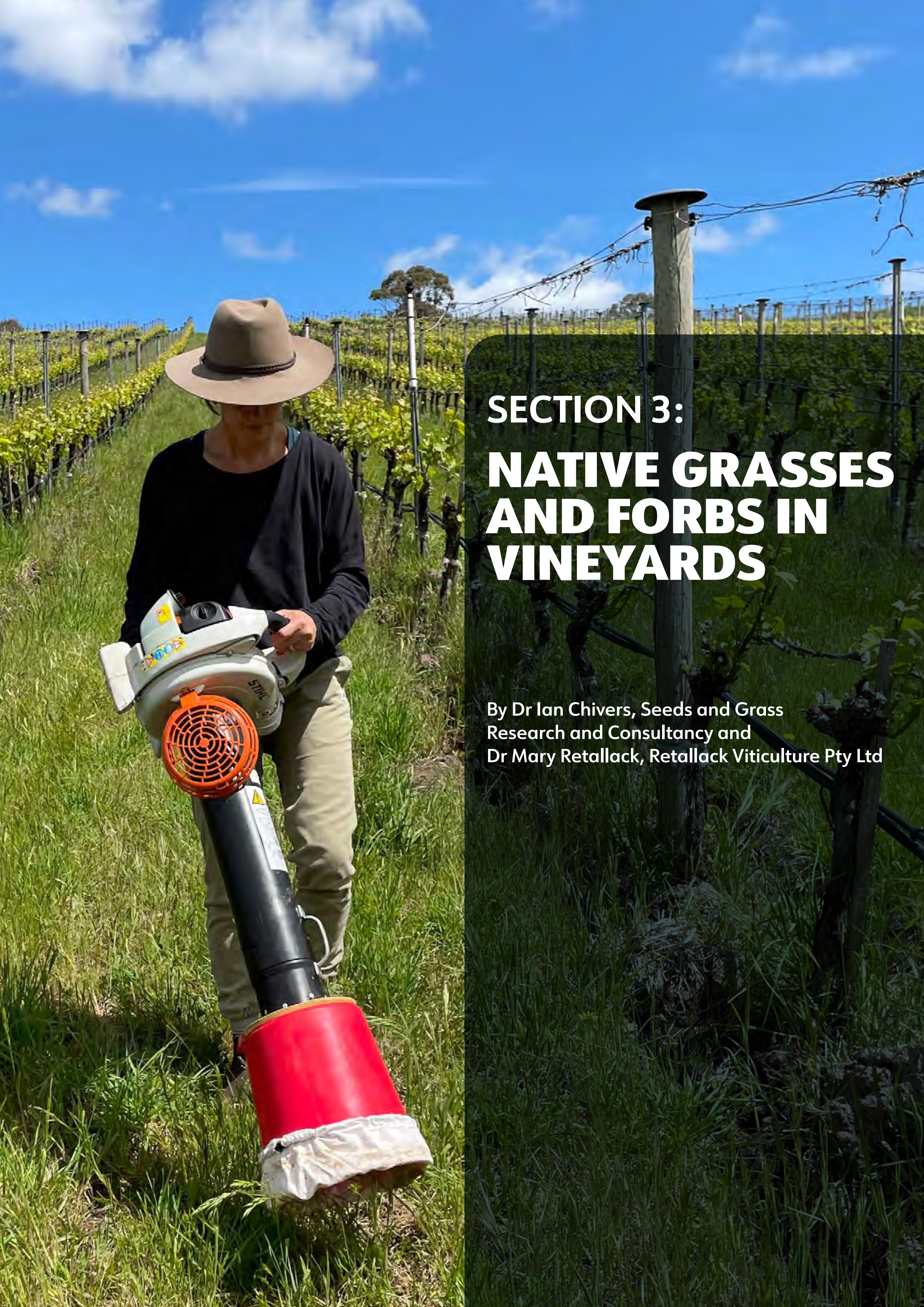
The addition of extra products, such as eggs or meat, which can be produced in conjunction with livestock grazing on ground covers can help diversify the business and is easily promoted on-site.

Furthermore, adding flowering species for cut flowers, edible plant species, or botanical plant species (gin, etc) into the biodiverse mixes within and around the vineyard also offer the potential for further value adding to the business. Bee hives can also be added to provide another income stream and enhance biodiversity. The aesthetic value of the enhanced biodiversity within the vineyard, and the improved 'paddock-to-bottle' regenerative management approach is also likely to attract customers and economically boost the business.

Summary

Increasing vineyard biodiversity by using multispecies ground covers and vegetation plantings is emerging as a viable strategy to improve plant and soil health, ecosystem function, profitability, and sustainability. In addition, the business may benefit from product diversification, carbon or biodiversity credits, and the social licence and regulatory approval from consumers and supply chains to sustainably continue producing wine and other products through enhanced regenerative agriculture practices.

Figure 48. The dynamic nature of ground covers in and around vineyards [Photo: Karen Thomas].



SECTION 3:
NATIVE GRASSES AND FORBS IN VINEYARDS

By Dr Ian Chivers, Seeds and Grass Research and Consultancy and
Dr Mary Retallack, Retallack Viticulture Pty Ltd

GENERAL PRINCIPLES

Before talking about the native species that might be planted/sown in a vineyard it is important to consider the principles that apply generally to the use of ground covers, both in the mid-row and under vines. Ground covers provide a myriad of benefits to vines, many of which interact to further enhance conditions.

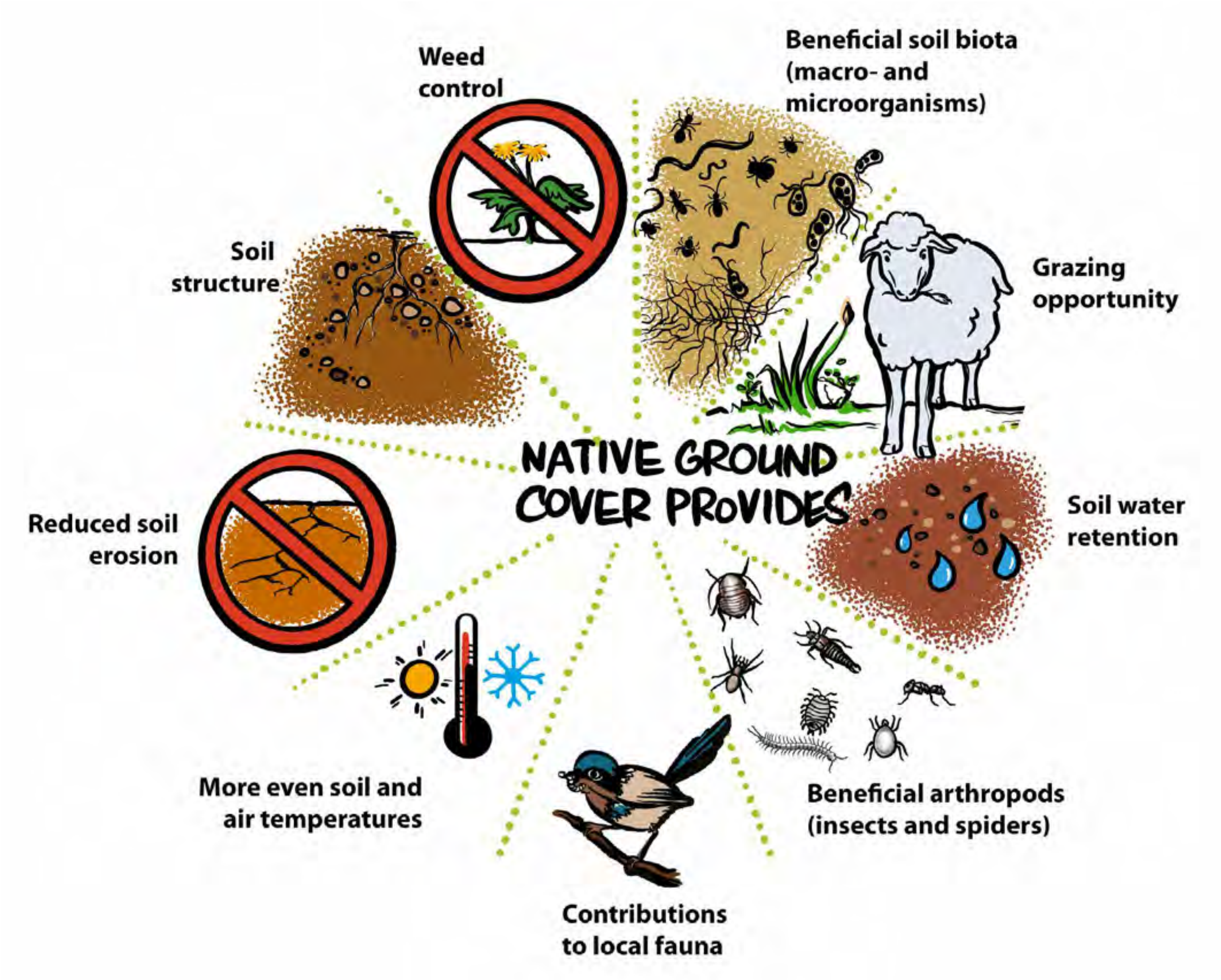


Figure 49. A few of the benefits of native ground covers in and around vineyards.

The importance of each of these will vary from vineyard to vineyard, but any one of these benefits is potentially very significant and likely to have a major influence on vineyard profitability:

- **Weed control:** Full ground cover will make the intrusion of weeds less likely and less impactful.

  An established ground cover will reduce weed seed germination rates and provide more competition for the water and fertility desired by weeds. While native grasses do not compete well with weedy species during their establishment, once established they outcompete most weeds, including salvation jane, wire weed, and evening primrose.

- **Beneficial soil bugs/soil biota:** Ground cover provides a good environment for soil biology to thrive, and they do lots of work in enhancing soil structure, recycling nutrients, and retaining moisture.

  Australian native species are particularly valuable. Gaskin et al. (2008) found native grass cover reduced soil pollutants by more than eight times when compared to introduced ground covers and by more than 20 times versus bare ground. They do this through providing a better soil environment for soil microbes and biology than introduced grasses – a real advertisement for native grasses.

- **Grazing opportunity:** Having a ground cover of palatable grasses can provide an opportunity to graze sheep throughout the vineyard, especially over the winter.

  This reduces or eliminates the need to mow and reduces operating costs – as well as potentially earning an income through agistment of stock.

- **Water retention in soils:** Bare soil loses moisture at alarming rates in hot weather, by providing a ground cover this will reduce these losses.

  This occurs through higher soil carbon levels that are required to hold greater amounts of soil moisture. Also, through better soil structure and via the roots of native plants which increase water penetration and availability of greater soil moisture at depth. The ground cover itself uses some water, but far less than the losses from bare soil. Good species selection of locally adapted ground covers will match the likely water availability with the needs of the ground cover, which is often less for native species compared to introduced species yet still allows plenty of moisture to remain within the topsoil.

- **Beneficial insects:** Many studies have shown that beneficial insects will live within the ground cover.

  For example, Retallack (2019) found 38 morphospecies of predatory arthropods in association with *Rytidosperma* spp. wallaby grasses, including wolf spider, brown lacewing, Pacific damsel bug, European earwig, assassin bug, shield bug, and ground beetles. These insects range away from their homes to find food and contribute to the biocontrol of grapevine insect pests, including economically damaging grapevine pests, such as light brown apple moth (LBAM), mealybugs, and grapevine scales.

- **Contribute to local fauna:** Many locally threatened species of insects, birds, and reptiles are dependent upon native ground covers, and they also enhance the surrounding environment.

  For example, the threatened *Synemon plana*, golden sun moth which is highly dependent upon wallaby grass in south-eastern Australia for its existence. Wallaby grass was once found extensively throughout southern Australia in large spreads but is now reduced to small remnants or small numbers of individual plants. Providing a wallaby grass ground cover in a vineyard will give the golden sun moth a place to live that it might not otherwise have. Other vulnerable insects, insectivores, and seed-eating birds are similarly supported by adding native ground covers into vineyards.

- **More even soil and air temperatures:** Full ground cover will lower soil and air temperatures.

  This is achieved by reducing reflected heat, retaining more soil moisture, and emitting water into the air as it cools itself down during summer. Equally, a ground cover will keep soil temperatures slightly higher in winter (and potentially reduce frost risk) through physically protecting soil and through the more vibrant soil life.

- **Reduced soil erosion:** Bare soils are highly susceptible to erosion by wind and water.

  Massive soil losses can occur through both high winds and heavy rainfall events – losses that cannot be quickly or cheaply recovered. Providing a full ground cover will slow water and wind movement, will trap fine particles, and will substantially reduce erosion. Wallaby grasses have a fibrous root system that helps stabilise sandy soils.

- **Soil structure:** Constant cultivation of soil reduces soil structure and increases compaction, which substantially and severely restricts water and nutrient flow through soil.

  This has a negative impact on root growth and the yielding potential of vines. Provision of a strong perennial ground cover will create superior soil structure through establishing pathways for water and nutrients to move through the soil and adding soil organic matter that creates desirable soil crumbling.

On the upside, a bare soil with a low weed seed burden provides good preparation conditions for the establishment of native grasses and forbs which are naturally adapted to a site.

Figure 50. The scorched earth approach is not what we are looking for – exposed soil with no life and subject to erosion (but good preparation for sowing native grasses) Photo: Ian Chivers].

WHAT TYPES OF GROUND COVERS ARE THERE?

A ground cover of noxious weedy species is still a ground cover, so why do we need to distinguish? Well, some are better than others and trying to find the perfect ground cover is not that difficult.

The key criteria for selecting functional ground covers include:

- **Perennial:** Living for many years, rather than just living for one year or less, allows for real benefits to flow to the soil and environment of a vineyard.

  An annual ground cover will often last less than nine months and will achieve some of the benefits given above, but not all, and many of those benefits will be transient only. For example, the addition of organic matter from an annual cover may be significant but will mostly be on the soil surface and will not incorporate into the soil to any great depth.

  A perennial cover creates conditions that result in the organic layer reaching a greater depth, as it is present for a longer period and can be incorporated by earthworms and other soil detritovores. Similarly, it produces more roots, which go through their annual cycle of death and renewal thereby leaving dead organic matter in the soil; the structure provided by the persisting root system also establishes strong soil binding and aggregation characteristics which aid soil structure.

- **Native:** There are many benefits to using native species that are naturally adapted to local conditions; many predatory arthropods are also native and have co-evolved with native flora and are found in association.

  Native grasses aid the local biodiversity and enhance the local environment. They will persist when many introduced species will not, they require less fertiliser (if any) than most introduced species, they are not weedy or likely to become problems on their own and, if you choose correctly, they will not require much maintenance at all.

- **Suited to the local environment:** Native species that occur within the environment or nearby are likely to be able to tolerate the usual extremities of weather that a locality will experience.

  There is no need to be too fussy about this by choosing only species that occur on that property. Find species that can grow in similar regions, or when we consider that the climate is changing to make our vine-growing regions drier and warmer, choose those that are able to grow in harsher regions.

- **Functional group(s) that works for you:** This is a bit of terminology, but essentially it means that you need to choose a plant type that fits in with your needs and provides functional benefits.

  The groups are broad-scale collections of species, such as 'cool-season perennial grasses' or 'warm season forbs', with plants within each group sharing similar characteristics of peak season growth, stature, and metabolism.

Grasses provide many benefits for several reasons:

- We know a lot about them. We know their germination and establishment patterns, their herbicide tolerances, and their fertility needs.
- They have relatively short time periods to germination, especially when compared to many forbs.
- Seed is available where it is not commonly available for the forbs.
- The grasses usually become the dominant functional group in plantings where multiple groups are sown at the same time.
- Grasses can be easily over planted at future times to introduce other species if desired.

Polyculture versus monoculture

A monoculture is where only one species of plant occurs in a place, much like a wheat crop, while a polyculture is where many species occur in a location, like most pastures or remnant forest areas.

In general, a polyculture is better able to tolerate a wide range of weather conditions and will, if it is a full mix of species, have some actively growing types throughout the entire year. Even a perennial has times in the year when it is not growing, or is growing very slowly, and often another species of plant will have a different growth period, which can mean that it is growing when the first species is not.

Similarly, if an adverse event occurs (say an attack of a pest or an unexpected severe heatwave), having more than one species in a ground cover can provide a little more flexibility in response to that event.

Figure 51. Monocultures of wallaby grass (left) and weeping grass (right) [Photos: Ian Chivers].

Ideally, we would establish polyculture ground covers with combinations of many different species from a range of plant functional groups. We might, for example, establish a combination of legumes, grasses, and herbs, which would give us a wide range of adaptations and attributes for a long-lived ground cover, like what has occurred in native grasslands for many millions of years across much of Australia. Australia has been largely a grassland for eons, and it has persisted as complex associations of many different plant types, but sadly they have largely been replaced by sown crops and pastures.

However, a monoculture is not necessarily a bad thing from a management perspective as it is easier to manage, since the periods of peak and least activity are known and predictable, weed control is simpler and establishment is easier since the germination and early seedling needs of only one species needs to be considered.

Given that we face an enormous background level of weed competition in all our sowing efforts, it is suggested to establish a monoculture of grasses, since we know the methods that ensure broad leaf weeds are controlled within grasses. We will talk much more about weed control in the next section of this guide. It may be best to achieve a polyculture is to establish a grass monoculture and then to progressively introduce other species once the weeds are under control.

Weeds and their impact on establishment

Virtually all failed native grass and forb plantings come down to losing the battle against weeds during the establishment phase.

In most environments there are roughly 20,000 seeds per square metre in the top layer of soil. Regardless of the environment, there are always plenty of seeds in the soil just raring to germinate when the right conditions occur. If our ground preparation for sowing is a simple cultivation and no more, then we are setting up the 300 to 500 seeds that we sow against a potential competition of 20,000 seeds per square metre.

Unless our seeds are the fastest to germinate and have the most vigour then they will simply be overwhelmed. The result will be poor with mostly weeds getting established and very few of our desired plants being visible.

It is important to remember here that Australian native grasses, indeed Australian plant species broadly, evolved under conditions where there were very few fast-establishing and fast-growing weeds.

With only a few exceptions, native grasses are slow to germinate (it may take 12 to 18 months to see a flowering stand) and have relatively low seedling vigour, so they are poorly equipped to complete at the seedling stage with the wide range of weeds that they now face. To get good establishment of our sown seeds, we must do what we can to tip the balance in their favour.

One of the reasons native grasses may take longer to establish is that they put their resources into growing roots and will only grow vegetation aboveground once the underground parts are established.

Figure 52. Vegetative growth above ground may not equal plant growth below ground

Seedbed preparation

So how do we go about reducing the 20,000 by orders of magnitude and give ourselves a chance?

This can be done by a few different approaches that often include short-term pain for long-term gain:

- Frequent cultivation to promote waves of germination of weedy species followed by another cultivation event, allowing sufficient time for most germination to occur at that time.
- Repeated herbicide use to essentially do the same as for cultivation, except that the soil is not disturbed. The herbicide can be an organic herbicide or a synthetic herbicide, that is the choice of the operator. Both will likely have negative short-term effects on the living components of the soil.

  However, it is possible to feed the soil with microbe food, such as fish hydrolysate, fulvic acid, seaweed products, and/or worm vermicasts, to encourage the soil life as soon as possible after disturbance.
- Combinations of these two. This is our favoured approach as the cultivation events bring fresh seeds up to the germination zone, exposing them to light and often starting their germination process, while creating a seedbed for the later sowing event. The combination with herbicide applications means that the soil structure is not being compromised.

This approach is best undertaken over several seasons, probably up to a year prior to sowing the target species with an alternating rhythm between cultivation and herbicide use.

So, it might go like this from starting with a weedy plant cover:

1. cultivate the weed plants into the soil
2. allow weeds to germinate and grow to 100 mm high, then kill off with herbicide (say two months after cultivation)
3. allow weeds to germinate and grow, then kill off with a cultivation (a further three months later)
4. repeat the above two steps
5. the final cultivation sets the soil up for sowing of your target crop.

In the figure below, note that the row to the side is not cultivated so that vineyard operations can occur without damaging the seedlings. These rows will be sown the year after

Figure 53. Soil prepared for sowing [Photo: Ian Chivers].

A variant of this approach is to sow a mulch or green manure crop with the aim of it establishing and growing a little before incorporating it into the topsoil. In the incorporation process all the weeds that germinated along with the mulch crop will also be killed and worked into the soil. This adds a little more organic matter into the soil.

The most important point here is that at no time should any of the weeds that germinate be allowed to set seed as that simply undoes what you have been trying to achieve. It is prudent to remove the flowers of weedy species before they set new seed.

There is an approach called 'soil scalping' where the entire top layer of the soil is removed and with it the weed seeds. We do not advocate this approach for large-scale operations as it is not cost effective and simply throws away the best and most fertile part of the soil in which your other plants are growing. It does allow for establishing a polyculture at one time but seems to us to have too many downsides for widespread use.

Soil type influences

While soils within a vineyard are seldom uniform throughout, usually they can be divided into two categories:

- mostly dry during summer and autumn
- often moist at those times.

In the former, the overriding need is to provide a ground cover that is not competitive for water with vines so that all, or most, of the applied irrigation is going to the vines and not the ground cover. In this scenario a grass that is dormant, or close to it, during summer will serve the purpose best.

For example, wallaby grasses tend to stop growing once they have set seed in late spring or early summer when soil moisture is limited. They will stay green if irrigated in the vineyard under-vine area.

In the latter case, which is less common, where soil tends to remain moist, a ground cover can aid grape quality by removing excess water from the soil. In this scenario, a grass that is actively growing during summer will extract moisture from the profile and help to achieve the desired result.

The need for either the removal of moisture by a ground cover or just having a persistent ground cover that does not compete at all for moisture drives part of the process of selection of grass species. Other factors include the soil sand/clay/loam mix, and which one is dominant, the likelihood of salinity in the soil or irrigation water, the location, and the desire to grow a mulch cover for spreading onto the vine rows.

Choice of species to sow

There are many hundreds of species of native grasses in Australia. Most are not suited to use in vineyards due to their growth habit, but some are highly suited. We discuss some that have the right stature for vineyard use below, that are not too tall or bulky, and have other useful traits.

These comments are largely based on Dr Chivers' observations, not purely on data from replicated trials although for some species, such as *Microlaena stipoides*, weeping grass, they are based on many hundreds of observations, some of which were under replicated trial conditions. For some of these types, there is a degree of projection where observations in one environment are applied to other environments.

***Rytidosperma* spp. wallaby grasses**

A special note here regarding wallaby grasses. We often treat plants called wallaby grasses as one species when, in fact, there are 35 species, all distinct from each other. Some grow in vastly different environments to others and so, for convenience, we have divided a small selection from the genus of wallaby grasses, Rytidosperma (here abbreviated to R) into two parts:

- those that grow in **wet environments** and those that grow in **dry environments**
- there are some that grow well in wet and dry environments, so we have included them in both groups

To make it harder still, the names are only botanical names as many do not have common names.

Wallaby grass group A: Dry area types (most of the genus) *R. caespitosum, R. richardsonii, R. carphoides, R. setaceum, R. bipartitum, R. erianthum, R. geniculatum. Rytidosperma erianthum*, hill wallaby grass and *R. geniculatum,* kneed wallaby grass grows < 30 cm and are well suited for use in the under-vine area.

Wallaby grass group B: Wet area types (far fewer) *R. duttonianum, R. laeve, R. tenuius, R. caespitosum, R. fulvum, R. bipartitum.*

Figure 54. Kerri Thompson and Brendan Pudney admiring their multispecies stand of wallaby grasses at Skillogalee, Clare Valley, South Australia [Photo: Mary Retallack]

Table 6. Functional group, scientific name, common name, and season of peak growth for a range of native grasses, forbs and lilies that are commonly sown in Australia.

Functional group		Family		Scientific name	Common name	Carbon pathway
1	Grasses	1	Poaceae	*Anthosachne scabra*	native wheat grass	Cool season grass (C_3)
				Austrostipa sp.	spear grass	
				Rytidosperma bipartitum	wallaby grass	
				Rytidosperma caespitosum	ringed wallaby grass	
				Rytidosperma carphoides	short wallaby grass	
				Rytidosperma duttonianum	brown-back wallaby grass	
				Rytidosperma erianthum	hill wallaby grass	
				Rytidosperma fulvum	wallaby grass	
				Rytidosperma geniculatum	kneed wallaby grass	
				Rytidosperma laeve	smooth wallaby grass	
				Rytidosperma racemosum	slender wallaby grass	
				Rytidosperma richardsonii	wallaby grass	
				Rytidosperma setaceum	small flowered wallaby grass	
				Rytidosperma tenuius	purplish wallaby grass	
				Microlaena stipoides	weeping rice grass	
				Aristida behriana	bunch wire grass	Warm season grass (C_4)
				Bothriochloa macra	red grass	
				Chloris truncata	windmill grass	
				Dichanthium sericeum	silky blue grass	
				Digitaria brownii	cotton panic grass	
				Enteropogon acicularis	curly windmill grass	
				Enneapogon nigricans	bottle washers	
				Enneapogon robustissimus	nineawn grass	
				Themeda triandra	kangaroo grass	
2	Herb	2	Amaranthaceae	*Atriplex semibaccata*	ceeping saltbush	
		3	Apiaceae	*Eryngium ovinum*	blue devil	
		4	Asteraceae	*Calocephalus citreus*	lemon beauty heads	
				Chrysocephalum apiculatum	common everlasting	
				Chrysocephalum semipapposum	clustered everlasting	
				Helichrysum scorpioides	button everlasting	
				Vittadinia gracilis	woolly New Holland daisy	
		5	Convolvulaceae	*Convolvulus angustissimus*	Australian bindweed	
		6	Haloragaceae	*Gonocarpus tetragynus*	raspwort	
3	Legume	7	Fabaceae	*Kennedia prostrata*	running postman	
				Lotus australis	Australian lotus	
4	Lily	8	Asparagaceae	*Arthropodium strictum*	chocolate lily	
				Bulbine bulbosa	bulbine lilly	

The following figure presents suggestions on how best to fit the small selection of eight common types of native grasses into the varying soil characteristics.

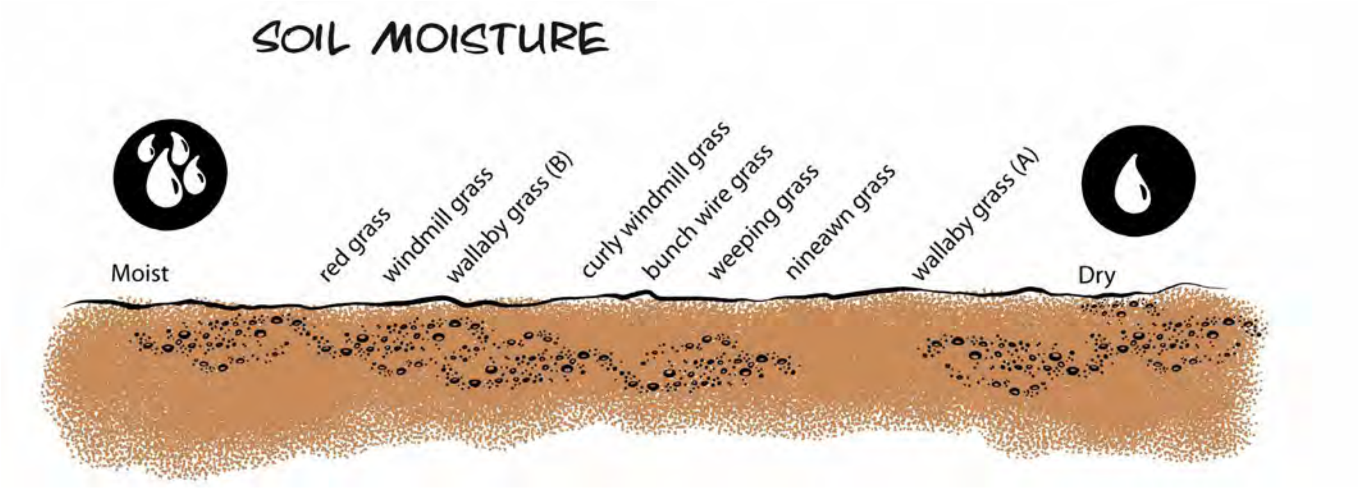


Figure 55. Soil moisture preferences of common native grasses.

Red grass, windmill grass and some of the wallaby grasses are often found in damp or frequently inundated areas. They would serve well to remove water from those areas of a vineyard that remain moist.

Wallaby grasses group A are very well suited to the driest areas that do not retain moisture for any significant length of time.

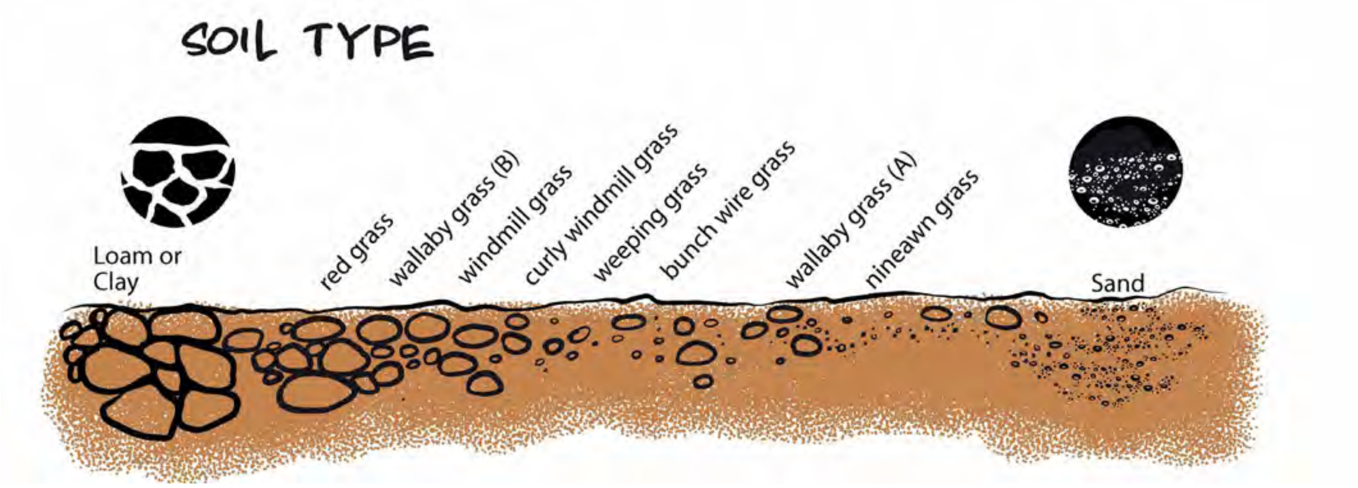


Figure 56. Soil type preferences of common native grasses.

Red grass does not grow on sandy soils and even prefers soils with no sand content at all, whereas nineawn grass seems to grow only on sandy soils, or those dominated by sand. The others have varying degrees of preferences but are not as fixed in what they prefer.

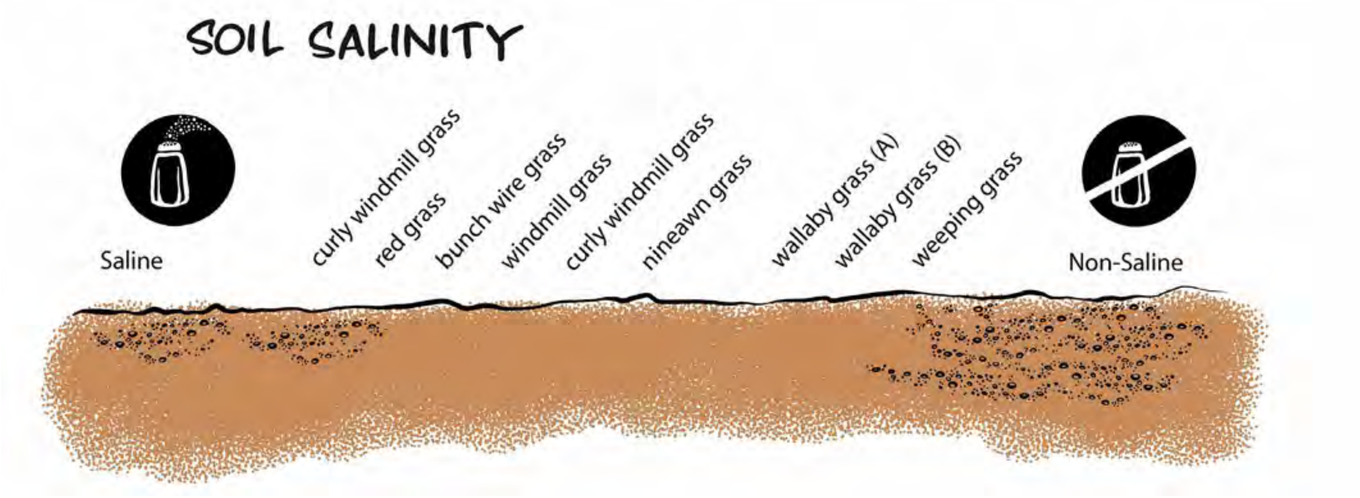


Figure 57. Soil salinity preferences of common native grasses.

Curly windmill grass is quite tolerant of soil salinity and can colonise saline scalds if provided with suitable germination conditions. Red grass is surprisingly tolerant of saline and contaminated soils and has been found growing in mine tailings that are often full of toxic chemicals.

At the other end of the scale, weeping grass seems to be very poorly tolerant of soil salinity, and the wallaby grasses are not highly tolerant either. However, there is a strong likelihood that individual varieties of both weeping grass and wallaby grass will have tolerance to salinity arising from their high genetic variability. There is enormous variability within these species for characteristics such as tolerance to herbicides and speed of germination.

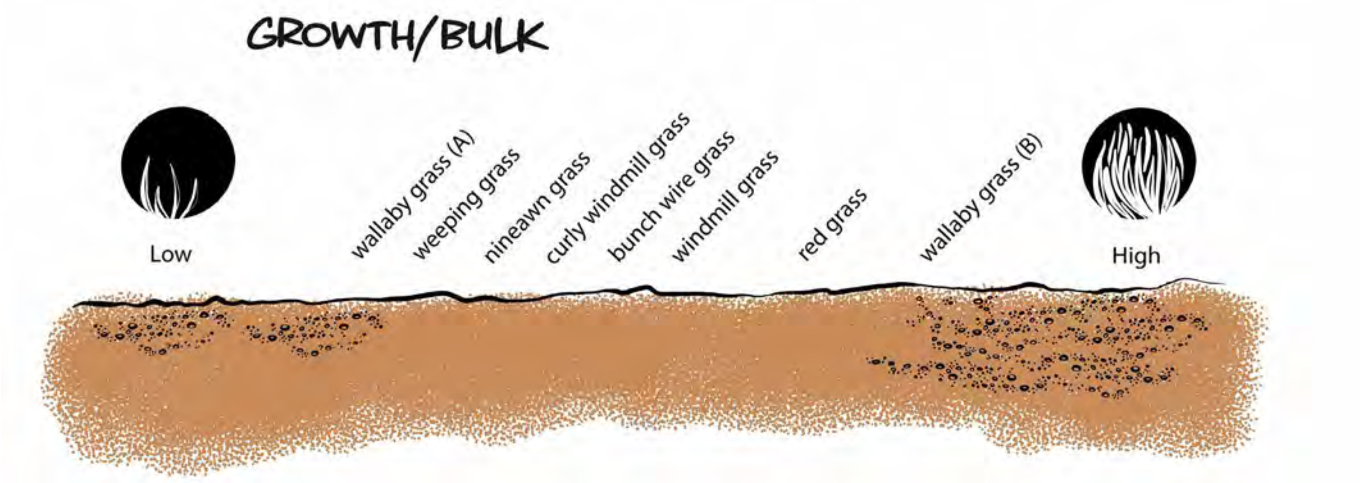


Figure 58. Growth or bulk production of common native grasses.

Low bulk grasses are particularly suited to those vineyard applications where all that is desired is a persistent perennial grass cover that is not going to be competitive with vines at any time of year for available water and nutrients.

High bulk grasses can be used in vineyards for several purposes: they may be sown in the mid-row space and mowed to the side to create mulch for weed suppression in vine rows; to add organic matter to soil where it is needed; or, possibly, to suppress some large and vigorous weeds.

ESTABLISHMENT OF NATIVE GRASSES

If there is adequate weed control, then you are now ready to sow the seeds of the desired species. Once again, there are several general principles that can guide you in getting the best results from your sowing.

1. Buy good quality seed

Unless you are harvesting your own seed from an existing stand, you will need to buy seed. There are several companies that produce native grass and forb seeds in Australia. They do so under managed conditions and, generally, they do a very good job with difficult-to-harvest seeds. Thankfully, things have moved on from times past when seeds were simply gathered in bulk from remnant stands with little, if any, weed control and no management applied to enhance seed vigour.

Seed specifications

When buying native grass seed, the buyer should insist upon a certificate that provides as many of the following pieces of information as possible.

- Source location
- A seed count i.e., the number of seeds per 100 g
- An indication of the amount of chaff (outer parts of the seed including the awn and hairs) you are buying.

  It could be as high as 95% chaff and only 5% seed which is ok if you know that and factor that into how much you are paying for the seed.
- The presence of weed seeds and, if possible, what they are.
- The viability of the seed.

  There are, commonly, two measures: the percentage of the seeds that are viable and could germinate (usually based on a Tetrazolium or TZ test) or, better still, a germination test that shows how many seeds are likely to germinate if the sowing conditions are good.

  These two tests can differ significantly as sometimes a seed might be viable and capable of germinating at some time but may not do so as it is dormant for the time being, with dormancy for some species possible for up to two to three years.

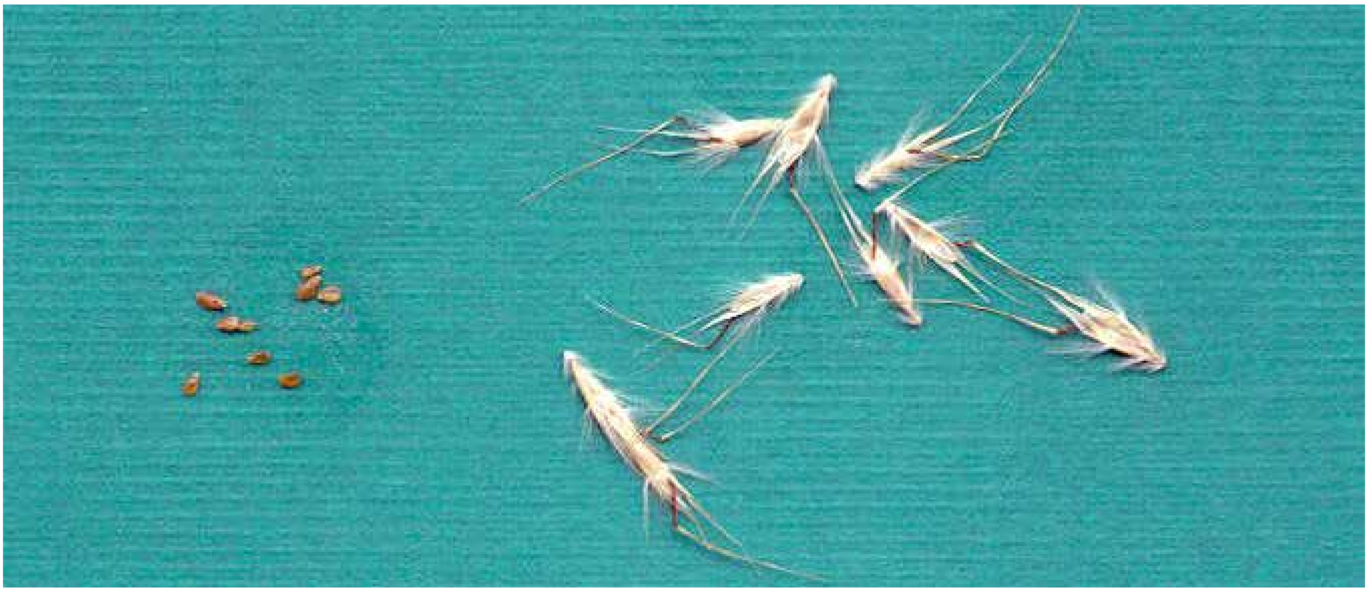


Figure 59. Note the size difference between cleaned wallaby grass seed (left), and chaffy seed with the awn and hairs intact (right) [Image: Ian Chivers].

2. Sow at the best time of year for that species

The cool season types can be sown in autumn or spring, or even winter if frost is not likely. The best results are achieved when soil is warmish, and moisture is plentiful though not flooded.

If you are sowing in autumn, you will be reliant upon autumn rainfall, which for many areas is unreliable. It will also mean that you have small seedlings through winter and vehicular traffic is very damaging on some seedlings, especially wallaby grass.

Early spring sowing can give good results and faster development from the fragile seedling to the more robust young plant before the main activities of the vineyard. It can also provide a longer window to control weeds during winter.

The warm season types can be sown at any time from spring to early autumn. The soil needs to be warm but not necessarily moist at sowing. These seeds seem to be able to germinate in response to summer/autumn rainfall events of greater than 20 mm.

It is often surprising how many warm season grass seedlings can germinate in autumn as, conventionally, it is felt that the only time of year to sow these grasses is spring. Spring sowing is more certain and probably gives the most reliable results.

There is no sense in sowing warm season grass seed in mid-winter as it will not germinate for months, and you will have a problem dealing with weeds without the option of using cultivation until the germination window in late spring. Almost equally, there is little point in sowing a cool season grass seed during summer as these seeds need almost constant moisture to germinate, which will happen when evaporation rates diminish in mid- to late-autumn.

3. Sow with rainfall

It is unlikely that irrigation will be available to the sown seed in the vineyard mid-row. This means that all the moisture needed for germination is going to be coming from rainfall. For the cool season grasses of wallaby grass and weeping grass, there is a need to have constant moisture around the seed for good uniform germination. For the warm season grasses, this is less important as they can germinate with pulses of rainfall from a summer storm or two.

4. Get the seed into the soil

Having the seed on the surface will limit how much of that seed will germinate. Having it just below the soil surface will massively multiply the rate of germination. Sow seed to a depth of 5 to 10 mm. This does not mean that you need to have expensive equipment that precisely measures the seed cultivation depth, as happens in grain crops or broadacre.

This can be achieved by simply dragging a sheet of weldmesh or a gate over the broadcast seed. While this isn't a method with high precision, it achieves a good result, and the key is that the soil needs to be cultivated and a bit soft or crumbly to be moved around by the mesh or gate. A final cultivation just prior to sowing is an important step in creating a suitable seedbed; it allows the seed to find little niches below the surface where it can be surrounded by soil and where moisture will hold onto both the soil and the seed.

5. You do not need specialised equipment

It is possible to sow large areas (i.e. 25 ha) by hand. This can be as rudimentary as throwing seed out of the back of a moving ute tray or it might be broadcasting the seed using a fertiliser spreader. Or it could be simply using a bucket and spreading the seed like you are 'feeding the chooks'. Many people get hung up on the need to adapt equipment to get these seeds out and miss the window for sowing, do not fall for this mistake and simply get the seed out. Remember nature will find a way!

Figure 60. Hand broadcasting native grass seed [Photos: Ian Chivers].

It is possible to sow species that tend to be quite chaffy, clump together to block sowing tubes, and do not spread easily by blending them with some inert matter. For example, vermiculite, rice hulls, and Dynamic Lifter work successfully if most of the final mix is the inert carrier. Often a ratio of 5:1 or 7:1 of inert matter to seed is required to get it to flow through a pipe. The seed and inert matter must be thoroughly mixed to disentangle any clumps of seed.

Chaffy refers to the large amount of loose or attached awns and other seed structures that are not the actual seed, such as adherent lemmas (the outer bracts at the base of a grass spikelet) and paleas (the inner of two bracts surrounding each floret in a grass spikelet).

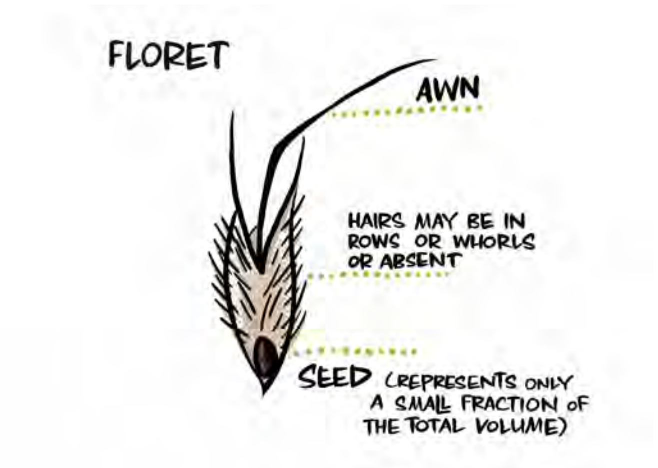


Figure 61. Native seed with morphological features highlighted including the size of the seed compared to the size of the floret (left), and corresponding floret (right) [Photo: Mary Retallack].

Until we develop good methods of removing the awns and fluffy material from around the seeds to make them easier to sow and flow through pipes, we are stuck with this limitation. There is some work happening on this front (flaming the awns and fluffy material off the seed) and we are hopeful that we will see methods of preparing the seed that will not only make them simpler to handle but also enhance their germination. In the meantime, we can take some comfort from knowing that those pesky chaffy bits aid germination by helping to retain moisture around the seed.

6. Applying mulch?

Should mulch be applied over the seed? This is a question that arises regularly, especially when there is little topsoil and getting the seed into the soil is difficult. The answer is usually 'yes'.

Mulch placed over the seed has repeatedly shown to enhance germination, particularly surface-sown seed, and if the mulch layer is not deeper than 25 mm the seedlings will push through the mulch and go on to produce good plants.

Hydroseeding vs hydromulching vs air-delivered mulch

Hydroseeding is a very common method of rehabilitation where seed is sprayed out in combination with paper mulch, glues, and dye.

Hydromulching is similar except the paper is replaced with a mulch and usually becomes a much thicker layer. Air-delivered mulch provides a much deeper (again) layer of mulch in which the seed is blended.

There have been repeated failures of sowing native grasses with hydroseeding, and it often appears that the seedlings are simply not strong enough to burst through the paper and glue matrix.

In rehabilitation conditions, the cereals and other bigger grasses have such high seedling vigour that they can punch through this layer, but the same cannot be said for native grasses. The best results have always been with the air-delivered mulch where a deep and soft layer of mulch is applied. This seems to create ideal germination conditions for native grasses.

Figure 62. Air-delivered seeding [Photos: Ian Chivers].

Figure 63. Hydroseeding (left), hydromulching (right) [Photos: Ian Chivers].

7. Use every window for weed control

The key to getting good results with a sowing of native grasses is to ensure good weed control. This is primarily achieved prior to sowing, but there is also another window that can be used to control weeds and that is the relatively small window between sowing and germination. This may be a period of 14 days or so, and during this period it is possible to apply a herbicide to kill off any weed seeds that have germinated in that period without doing any damage to the not-yet-emerged seedlings.

A very useful idea is to mark out a small strip (say a metre long) within the sown area that is easily accessible and to sow it heavily with the seeds of your sown native grass. This acts as your indicator to germination. You can visit this area each day or so, check germination, and have confidence that the seeds in the larger area will reflect what is happening in the strip.

If there is nothing happening in the strip, then there is not going to be much happening in the larger sown area. This will give you confidence to spray the larger area for any weeds that have germinated knowing that you are not killing off the seedlings that you are wanting.

It has the secondary purpose of providing a simple means of identifying the seedlings of the grass that you have sown and knowing what to look for across the broader area.

Figure 64. A simple row to be sown heavily between the two marker sticks [Photo: Ian Chivers].

The following pages are notes about the various native grasses that are commonly used for vineyards in southern Australia.

Bothriochloa macra, red grass or red leg grass

Where it occurs in the environment

Bothriochloa macra, red grass is often found in drain lines where runoff is assured. It is also found in very dry parts of the environment where it will survive for many months without rainfall, as long as the soil has a very high clay content. It does not grow on sandy soils as it relies upon a high clay content to retain moisture and nutrients for growth.

Figure 65. *Bothriochloa macra*, red grass can produce a very good lawn [Photos: Ian Chivers].

Natural forms

Bothriochloa macra tends to form monocultures where it is the sole plant type or most of the plant cover. It forms lawns very readily, which are very hardy, very shade adapted and require little maintenance.

Tolerances or attributes that make it valuable for vineyards

- It can grow under severe water deficit on clay soils, where it remains green and active whilst most other plants have died.
- It is tolerant of shading and can thrive growing under trees.
- It is quite tolerant of high levels of soil pollution, being able to germinate and grow on mine wastes that have been treated with cyanide and have high levels of heavy metals.
- Apart from removing the seedheads, there is little to maintain with this grass as it will not require fertiliser, lime, or irrigation once established.

Season of growth

It will enter a full winter dormancy once frosts occur, resuming growth in late spring. It will continue to grow until early autumn.

Has it been used in vineyards?

Its use in vineyards is mostly as a part of a native grasses seed blend.

How to sow, problems with the seed

The seed is chaffy, but not as problematic as some species as the seeds form a far higher percentage of the floret. Blending with a carrier, such as dried, pelletised chicken manure (which is fine even with the added nitrogen), or vermiculite, will aid in dispersal and help to achieve an even spread of seed.

Sowing rate, sowing time of year

Bothriochloa macra florets should be sown at 5 to 10 kg per ha to get a full coverage and it is best sown in spring, although autumn sowings have proven successful.

Seedlings and growth forms

Bothriochloa macra has a mostly basal form of growth with a distinct pattern of prostrate or close-to-the-ground vegetative growth and vertically rising reproductive growth that is largely void of leaves. Seedlings have relatively wide leaves, often with a reddish margin and tend to tiller rapidly in their early stages.

Any challenges?

Bothriochloa macra is a prohibited import into WA as it does not occur there naturally.

Figure 66. Red grass remains green even under severe water stress (left) and growing between rows of trees showing tolerance to shading and moisture stress (right) [Photos: Ian Chivers].

Figure 67. Mature red grass plant showing basal leaves and aerial seedheads (left), *Bothriochloa* roadside showing attractive red colouration in autumn (right) [Photos: Ian Chivers].

Chloris truncata, windmill grass

Where it occurs in the environment

Windmill grass is very widespread in its natural habitat and highly responsive to summer rainfall events or receiving moisture. This can be where water runs off following irrigation or an irrigation leak. After these events, windmill grass seems to appear from nowhere or rejuvenates from a semi-dormant state to spring to life and quickly produce both leaves and seedheads. So, it is often found in drains and on the edges of hard pavement where runoff is likely. It is also prevalent in wine regions with warm humid conditions and higher rainfall, like the Hunter Valley.

Figure 68. A young windmill grass plant can produce seedheads at a young age (left), and a mowed plant with limited seedheads (right) [Photos: Ian Chivers].

Natural forms

There are probably many forms of windmill grass in the environment with slightly different characteristics; however, this has not been well documented. It is important not to confuse windmill grass with couch grass heads that tend to be smaller in size.

Tolerances or attributes that make it valuable for vineyards

In summer, when windmill grass is actively growing, it can absorb a lot of moisture from soil, and remains a relatively short grass. It will continue to build up bulk close to the ground, but seedheads will not reach significant height. This means it is unlikely to become entangled with vine leaves. It can be mowed and will remain green.

Season of growth

Its active season of growth is summer with lesser growth in spring and autumn and virtually none in winter, depending on the incidence of frost that will send it into full dormancy.

Has it been used in vineyards?

It has been used in parts of some vineyards where the desire is to remove water from the profile to aid grape quality.

How to sow, problems with the seed

The seed of windmill grass is very small and very chaffy. Seeds will clump readily and will not flow through a tube if not treated in some manner. Blending with vermiculite helps to spread apart clumps; other inert products, possibly with smaller particles than vermiculite, can also work. The tendency to clump is very high and they need to be teased apart during the blending process. Air-delivered mulch systems, which dilute the seed down to a very low proportion of the mix work well.

Sowing rate, sowing time of year

Windmill grass is best sown in spring and can be sown on the surface, although it is best if it is incorporated in some manner. The sowing rate needs only be from 0.5 to 1.0 kg per hectare of the chaffy product as the seed is very small.

Seedlings and growth forms

Seedlings start very small but expand rapidly if rainfall or irrigation occurs. Although the species is a perennial, it can behave as an annual plant in some conditions; continued coverage is dependent upon having seed in the seed bank. So, let it set seed at least once every three years or so.

Any challenges?

In Western Australia windmill grass is frequently considered a weed and significant effort is made to remove it.

Figure 69. Mowed versus unmowed *Chloris* (left) and mowed *Chloris* remains green throughout summer (right) [Photos: Ian Chivers].

Figure 70. Profuse growth of Chloris truncata both vegetatively and reproductively [Photo: Ian Chivers].

Microlaena stipoides, weeping grass, weeping rice grass

Where it occurs in the environment

Microlaena stipoides is found in cooler, shaded environments where it can access some moisture throughout the year. In southern parts of Australia this can be in open conditions, whereas in more northern areas of Australia it is restricted to the tops of hills in rainforests. It will occur in the drier inland areas away from the coast but is usually restricted to the edges of rivers or creeks. It is tolerant to frost.

Figure 71. A young *Microlaena stipoides* seedling grows very extensive roots (left), and seedling plant showing multiple tillers (right) [Photos: Ian Chivers].

Natural forms

There are probably many thousands of distinct types of *Microlaena stipoides* owing to its longevity within Australia and its beautifully complex breeding system. Generally, this grass is a small clump grass with high leaf density and soft texture.

Within the array of types there are forms that have very fine leaves and others that are coarser. There are also types that are more upright while many are quite prostrate. *Microlaena stipoides* foliage tends to grow up to 30 cm with a flowering head up to 70 cm and is suitable to drive over or used in a commercial setting as a grassed area.

Tolerances or attributes that make it valuable for vineyards

The key attributes for vineyard use are that it is strongly shade tolerant, very long-lived once established, can be mowed to form a full turf, is drought tolerant, and has low fertility requirements.

Season of growth

While it is a cool season species it can produce green growth throughout the year in many environments. It will have its peak growth in very late spring and produce the bulk of its seed around late December/early January.

Has it been used in vineyards?

Microlaena stipoides occurs naturally in some vineyards and has also been sown in vineyards. It is particularly useful for vineyards where its low growth, its tolerance of mowing, and its persistence are preferred attributes.

Figure 72. A pure stand of *Microlaena stipoides* between the vine rows (left), and after regular mowing it forms a dense lawn (right) [Photos: Ian Chivers].

Figure 73. *Microlaena stipoides* suppressing weeds in the mid-row [Photos: Ian Chivers].

How to sow, problems with the seed

Microlaena stipoides seed has very small barbs along the back of its awn and for this reason is quite sticky and will clump together in any machine that tries to funnel the seeds down a narrow tube. It is possible to sow it by blending it with Dynamic Lifter (or a similar substrate) at a rate of 1 kg of seed to 7 kg of chicken manure.

Seed coating with clay has not been successful as it tends to make the seeds too large for the emerging cotyledon to push through.

Sowing rate, sowing time of year

As a pasture, the sowing rate is typically 30 to 40 kg per hectare. You may wish to start with a smaller area and allow the seeds to spread, which will result in new seedlings over time. It will often seed within the first year if there is adequate rainfall, but full seed production does not occur until year two and beyond.

It can be sown in autumn and spring, avoiding winter when its germination rate is very low except in warmer climates. Summer sowing will require significant rainfall or irrigation to keep the seeds moist.

Seedlings and growth forms

After germination and achieving two leaves, it will often have a very slow aboveground growth rate. It appears at this stage that it is rapidly extending its root system rather than its aboveground plant, but it will soon enough commence rapid growth and produce more leaves. It tends to produce more tillers rather than more bulk on the existing tillers and will do so for some months.

Any challenges?

It has slow winter growth which can be frustrating as it is often at that period that activity is desired.


Figure 74. *Microlaena stipoides* prostrate (left), and upright growth form (right) [Photos: Ian Chivers].


Figure 75. Spaced plants showing clump form (left), *Microlaena stipoides* unmowed and ungrazed still doesn't get very tall (right) [Photos: Ian Chivers].

Rytidosperma species, wallaby grass

Where it occurs in the environment

Predominantly, this genus of grasses prefers dry soil conditions, although several of the 35 species are well adapted to wet soils. They are species of the open plains and can occur in vast swards of many hundreds of hectares, although this is getting rarer due to cereal cropping. They are moderately adapted to shade and do grow under trees if the canopy is not to ground level.

Figure 76. Wallaby grass being a persistent ground cover in a mid-row (left) and wallaby grass growing vigorously in the mid-row (right) [Photos: Ian Chivers].

Natural forms

There are many natural forms of wallaby grasses that can be expected as this is a large genus. Some forms commonly reach well over 1 metre in height (foliage including flowering stalk), whilst others seldom exceed 10 cm. Usually, they are fine-leaved with long flowering stalks; plants are mostly quite dense with fibrous root systems. They are tussock grasses, so they tend to have gaps in between rather than the close density of a commercial grass stand.

Figure 77. A very small wallaby grass, *Rytidosperma erianthum* (left), and lawn from a mid-size wallaby grass (right) [Photos: Ian Chivers].

Tolerances or attributes that make it valuable for vineyards

Most species of wallaby grasses can tolerate long periods of dry soils and for this reason alone they work well in a vineyard mid-row and in the under-vine area. If the right species is sown it will remain small and be of very little competition to vines and yet still establish a significant cover that is competitive with weeds and provides habitat for predatory arthropods. *Rytidosperma geniculatum*, kneed wallaby grass has a low profile (< 30 cm including seed stalk) and is adapted well for use in the under-vine area.

Figure 78. Mowed wallaby grass in a mid-row after it has set seed in early summer (left) and wallaby grass seed has shattered to form a mass under the plants (right) [Photos: Ian Chivers].

Season of growth

Wallaby grasses tend to grow strongly through the cool seasons and grow very little during the hot months.

Has it been used in vineyards?

Wallaby grasses of various species have been used broadly in vineyards throughout much of southern Australia. Species commonly used are *R. caespitosum*, *R. richardsonii* and *R. geniculatum*.

How to sow, problems with the seed

Wallaby grass seeds are very chaffy, with at least two-thirds of their weight being light fluffy chaff (roughly 90% of the volume is chaffy). This makes them problematic to sow through any tube as they will bridge readily from one side of the tube to the next. Mixing with an inert material often works very well; vermiculite blends well with wallaby grass and tends to make the seed a bit more slippery, thereby aiding its flow.

Wallaby grass seed has frequently been pelletised with clay to make it flowable. This is a good technique if the buyer recognises that the seed component of the mix is now very significantly reduced. A lot of clay and binder is attached to the seed and will increase the weight of the seed by five times. It does help with the delivery of the seed but gives fewer seeds per kilogram than the fluffy, chaffy seed on its own.

The seed can be removed mechanically from the surrounding chaffy materials to make it easier to handle. The seed, then, is very fine and flows very readily. It should then be clay coated to add some water-holding capacity around the seed as this is one of the key functions of the chaffy parts of the natural seed.

Sowing rate, sowing time of year

A full cover on bare ground can be obtained using about 5 to 10 kg of seed per hectare. Wallaby grass recruits new seedlings if given the opportunity to seed and where the seed is somehow incorporated into the soil.

It is possible for wallaby grasses to produce more than 100 kg per hectare of seed once the grasses reach maturity in year 2 to 3 under good growing conditions.

Seedlings and growth forms

Seedlings are very thin and weak for at least a month after germination, and they are especially susceptible to vehicular traffic at that stage. So, if weed control can be held off until the wallaby grass is around three to four months old that will reduce the losses from traffic.

Any challenges?

Seed buyers should ensure that the species in the seed lot suit the purpose desired. Some merchants simply sell wallaby grass seed and do not specify species. It is prudent to seek these details.

The identification of wallaby grass species is primarily through the arrangement of awns and the other chaffy bits around the seed. So, if your merchant cannot provide the species name then get a sample of the seed and you are likely, then, to be able to work out the species it is/they are.

Figure 79. A mid-sized wallaby grass, *Rytidosperma richardsonii* (left), and a smaller wallaby grass, *Rytidosperma geniculatum* [Photos: Ian Chivers].

For more insights on growing wallaby grasses please refer to **Grower insights: Dan Falkenberg, Eden Hall Wines** and Utilising native grassland species in Australian viticulture.

FORB AND PROSTRATE WOODY GROUND COVERS

Some of the most beautiful, colourful, and exciting ground covers are those made from flowering herbs, or forbs. They create colourful displays when they flower and often have attractive foliage. They produce nectar and pollen that attract insects and birds, and they support abundant soil health. There are also types that can live under shading and in competition with a shrub or tree canopy. Furthermore, they form complex plant communities with grasses.

Figure 80. *Vittadinia* spp., New Holland daisy [Photos: Mary Retallack].

Forbs work well to provide a ground cover under vines like grasses. However, they are not as tolerant of traffic and grazing as grasses.

They are best added in after grasses when weed control of other broad leaf plants is well established and the seed bank of weed seeds is likely to be substantially reduced. This addition can be through either seed or by planting tube stock. In each case, there will be a need to create a seedbed for them within the grass sward. This can be a narrow trench or channel that might be only 40 to 50 mm wide, or it might be little divots placed within the sward.

Figure 81. *Scaevola aemula*, fairy fan flower [Photos: Mary Retallack].

The following insights on native forb establishment are provided with the assistance of Warren Saunders and Dan Ganter.

- If sowing by seed, you must ensure that the seed is fresh and preferably no more than three to four years old. It must be cleaned prior to storage as the chaffy seeds can often carry microscopic insects and other bugs that will infest and destroy the seed in storage. This can often be achieved simply by washing the seed with water and then redrying prior to storage. As for cleaning off the chaffy parts of the seed, it is not vital if they are clean of dust and bugs prior to entering storage.
- Commonly, these seeds are very small and will need care in placement. If the seed is retained in the chaffy form, then it will probably be easier to spread if it is blended with a high ratio of inert matter. A useful mix for inert matter would be sand with perlite and water crystals, or even straight potting mix.
- It is often an advantage to treat the seeds with smoke water prior to sowing to help to break down some of their dormancy. Smoke water has been shown to stimulate some seeds out of a lengthy seed dormancy stage, which may be up to a couple of years during which time the seeds will not germinate (this is a fascinating piece of science if anyone wants to look into it, see Dixon et al. (1995).
- Sowing is best when rainfall is likely rather than sowing into dry conditions that are likely to remain dry. It is suggested that a mulch layer be placed after sowing to cover the seeds and experience suggests that straw mulching is the best.

Figure 82. *Myoporum parvifolium*, creeping boobialla comes in a broad leaf, fine leaf, and purple leaf form [Photos: Mary Retallack].

Figure 83. *Myoporum parvifolium* creeping boobialla purple leaf form [Photos: Mary Retallack].

Figure 84. *Kennedia prostrata*, running postman [Photos: Mary Retallack].

Figure 85. Paper daisies have very attractive flowers and can blend well with grasses to provide colour and texture [Photos: Ian Chivers].

Figure 86. Common everlasting has very attractive small flowers (left), and a mixed cover of grasses and common everlasting (right) [Photos: Ian Chivers].

Table 7. Notes on certain species that have been considered for use as vineyard ground covers

Scientific name	Common name	Success from sowing seed?	Notes
Atriplex semibaccata	creeping saltbush	yes	quite easy from seed
Chrysocephalum apiculatum	yellow buttons/ common everlasting	yes	seed must be fresh
Geranium retrorsum	grassland cranesbill	yes	
Geranium solanderi	native geranium	yes	
Goodenia albiflora	white goodenia	yes, but seedlings are delicate	by cuttings
Goodenia pinnatifida	cut leaf goodenia	yes, but seedlings are delicate	by cuttings
Kennedia prostrata	running postman	yes	seed needs heat treatment prior to sowing
Kunzea pomifera	muntries	yes	very fine seed, sow shallow
Myoporum parvifolium	creeping boobialla	no	by cuttings
Ptilotus spathulatus	pussy tails	no	plants only
Scaevola aemula	fairy fan flower	produce very few seeds	by cuttings
Vittadinia spp.	New Holland daisy	yes	need to check that seed is viable


Figure 87. *Atriplex semibaccata*, creeping saltbush [Photos: Mary Retallack].

Additional information

For more information see our range of EcoVineyards fact sheets on the following topics:

- Insights on wildflowers and forbs from Western Australia
- Utilising native grassland species in Australian viticulture
- Functional biodiversity solutions for Australian vineyards, insights from Orange, NSW

FURTHER INFORMATION

Ground cover plants

- EcoVineyards: Journal articles on native insectary plants
- Lower Blackwood LCDC: Establishing multispecies and perennial pastures with Jade Killoran
- Landscape SA: Common native grasses
- Local Land Services: Common native grasses of central west NSW
- Lower Blackwood LCDC: Data collection to monitor pasture health and productivity
- Native Grass Resouces Group: That grass book by Ellen Bennett
- Penn State: Growing cover crops under vineyards vines is a sustainability strategy
- Wine Australia and University of Adelaide: Cover cropping decision support tool
- Wine Australia: The evidence supports the value of under-vine crops

Harvesting native grass seed

- Grass grabber: Grass seed harvester

Soil health

- Books
  - Dirt to Soil by Gabe Brown
  - For the love of soil by Nicole Masters
  - Growing a revolution by David R Montgomery
  - Holistic management handbook by Jody Butterfield, Sam Bingham and Allan Savory
  - Regenerative soil by Matt Powers
  - Teaming with microbes by Jeff Lowenfells
  - The hidden half of nature: The microbial roots of life and health by David R Montgomery
- EcoVineyards: Soil health indicators for Australian vineyards
- GreenCover Seed videos:
  - Secrets of the soil sociobiome with Dr Christine Jones
  - The phosphorus paradox with Dr Christine Jones
  - The nitrogen solution with Dr Christine Jones
  - Cover cropping for carbon capture in vineyards and orchards with Dr Christine Jones
- GreenCover: Soil health resource guide
- Lower Blackwood LCDC: Soil Secrets: The fundamentals for building profit, productivity and natural capital with Dr Christine Jones
- Podcasts
  - Nutrition farming podcastwith Graeme Sait
  - Quorum sense podcast hosted by Jono Frew
  - Regenerative agriculture podcast by John Kempf
  - Talkin after hours with the Lower Blackwood LCDC

- Soil carbon sponge
  - Biodiversity for a liveable climate: **The soil carbon sponge, climate solutions and healthy water cycles with Walter Jehne**
  - Investing in Regenerative Agriculture and Food: **Walter Jehne, stop talking about carbon emissions and focus on restoring the water cycle**
  - Regenerate Earth: **How hydrological processes naturally regulate and cool Earth's climate** by Walter Jenhe
  - Regenerate Earth: **Presentations**
  - Regenerate Earth: **Regenerate earth paper** by Walter Jenhe
  - Regenerate Earth: **Walter Jehne's Soil Carbon Sponge ABCD** Regenerative Agriculture Podcast: **Rebuilding the soil carbon sponge with Walter Jenhe**
  - The Regenerative Journey Podcast: **pioneering soil microbiology**
- Soils for life: **cropping resources**
- The Wisdom Underground: **Walter Jehne: clarifying climate history to find the right path forward** The University of Adelaide: **Soil carbon under-vine**
- Vidacycle's regenerative viticulture apps: **Sectormentor for vines** and **Soilmentor**

Weedy species

- Napa Green: **Weed management toolkit**
- EcoVineyards: **Weedy species - what do they tell us?**

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