CUT 1001: AO7 – Using cover crops to control vigorous vine growth

This is an excerpt from the final report CUT 1001: **Optimising industry returns from existing soil and water research.**

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Adoptable Outcome 7. Using cover crops to control vigorous vine growth

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1. Introduction

Overly vigorous shoot growth can occur when grapevines are grown at sites where soils are deep and fertile with a high water-holding capacity. This problem can be further exaggerated in environments with high rainfall, especially during the winter-spring period when shoot growth is most rapid and difficult to control. Shoot growth can also remain active late in the growing season resulting in substantial lateral shoot growth. The final result of vigorous shoot growth is a canopy with a high number of large, dark green leaves which leads to excessive shading of both leaves and fruit (Smart et al. 1985a, Dokoozlian and Kliewer (1995a,b). Shaded canopy conditions not only reduce solar radiation, but can also alter the ratio of short:longwave radiation, reduce leaf and bunch temperature, increase the humidity, and reduce the carbon dioxide availability as well as the photosynthetic and metabolic activity of the whole vine (Schultz and Lider 1964, Van Zyl and Van Huyssteen 1980, Smart and Robinson 1991). This in turn can lead to problems such as delayed fruit ripening and/or undesirable berry compositional properties which can impact negatively on wine quality (Smart et al. 1985b, Haselgrove et al. 2000, Spayd et al. 2002, Wilkinson et al. 2006). In addition, shaded canopies often increase the incidence and severity of disease (Rotem and Patti 1969), and reduce crop yields by lowering bud fruitfulness (Kliewer 1982) and increasing the level of bud and inflorescence necrosis (Perez and Kliewer 1990, Jackson 1990).

A number of viticultural techniques are used to address problems associated with excessive/high vine vigour. These include pruning and canopy management (Smart et al. 1990, Smart and Robinson 1991), high density planting (Buttrose and Mullins 1968, Archer and Strauss 1985), deficit irrigation scheduling (Goodwin 1995, Dry and Loveys 1998) and root pruning (Dry et al. 1998, Proffitt 2000). A further option is the use of cover crops to increase the competition for soil moisture and nutrients.

Cover crops by definition are plants (annual or perennial) used to cover bare ground between rows in vineyards. Those grown in Australian vineyards are generally introduced (exotic) species and include annual cereals (eg. oats, rye and barley), legumes (eg. field peas, faba beans, vetches, lucerne, medics and clovers), and annual/perennial grasses (eg. ryegrass, fescue, cocksfoot and phalaris). The majority of these are commercially available and are used because of the range of potential vineyard benefits they offer. These include soil health through their effects on physical, chemical and biological properties (Tisdall and Oades, 1979, Gulick et al., 1994, McGourty and Christensen 1998), weed suppression (Porter 1998, Fourie et al. 2006), reduction in water and wind erosion (White 2009), moderation of soil temperatures (Pradel and Pieri 2000), and improvements in invertebrate biodiversity (Whitelaw-Weckert et al. 2007, Thomson and Hoffman 2009, Danne et al. 2010).

Some cover crop species have also been shown to be useful in controlling vine vigour by increasing the competition for soil water (Van Huyssteen and Weber 1980, Morlat 1987, Caspari et al. 1997, Pritchard 1998, Proffitt 2000, Wheeler et al. 2005, Penfold et al. 2006, Tesic et al. 2007, Celette et al. 2008, McDonald et al. 2010) and nutrients (Tan and Crabtree 1990, Robinson 1992, Ingels et al. 2005). Indices of vine vigour such as the rate of shoot growth, canopy density and pruning weights are commonly referred to, with reductions in one or more of these parameters ranging from 10 to 70%. In many cases the soil water extractability of cover crops has assisted with implementing deficit irrigation strategies by accelerating the depletion of soil moisture from the

root zone. The final result is a smaller canopy which is easier and often cheaper to manage. In addition, there is generally an improvement in berry composition, which, in some cases, has resulted in improved wine quality.

It is clear from the literature that the success or otherwise of cover crops in manipulating vegetative growth largely depends on environmental conditions, the species of plant being grown, vine root growth characteristics and vineyard floor management practices. Where a key objective is to use cover crops to reduce vegetative growth, there is a need to consider how best to maximise the response. This document aims to provide the appropriate guidelines in the use of cover crops for situations where excessive vegetative growth is considered an issue.

2. The competitive nature of cover crops

Soil water extraction

The positive effect that some cover crop species have in reducing vine vegetative growth is driven primarily by their influence on soil water and nutrient availability. This is achieved through their ability to extract water, particularly in the upper 30 to 40 cm soil layer, prior to rapid shoot growth in spring (Morlat 1987, Caspari et al. 1997, Proffitt 2000, Landcare Group 2001, Lanyon et al. 2004, Wheeler et al. 2005, Monteiro and Lopes 2007, Tesic et al. 2007, Celette et al. 2008).

However, in order for cover crops to have a major influence on vine growth, vines must have a proportion of their root systems within the mid-row area. If roots are confined to the vine row through irrigation practices (eg. drip systems in low rainfall environments) or through lateral restrictions (eg. wheel track compaction), then the effect of cover crops on vine vigour is likely to be minimal (Smart et al. 2006). The root distribution of the vine and its capability to exploit the mid-row is therefore a key factor that will determine whether the desired reduction in vegetative growth is achieved or not. This should be assessed prior to establishing the cover crop. If they are restricted to the vine row then the use of cover crops to control vegetative growth may be ineffective.

Case study 1

The depth of water extraction is dependent on the root distribution of the cover crop. This was demonstrated by Proffitt (2000) using chicory (‘Puna’) and a perennial grass mix (3:1 cocksfoot/ryegrass) sown at a width of 1.5 m in order to reduce the vegetative growth of 15 year old Cabernet Sauvignon vines planted on a deep cracking clay soil in Coonawarra, South Australia. Within the first year of establishment, the chicory taproot reached a depth of 40 cm compared to a maximum depth of 20 cm for the grass roots. By the end of the second season, the chicory taproot had thickened and reached a depth of 60 cm, while the more fibrous grass roots had grown to a depth of 40 cm (Figure 1).

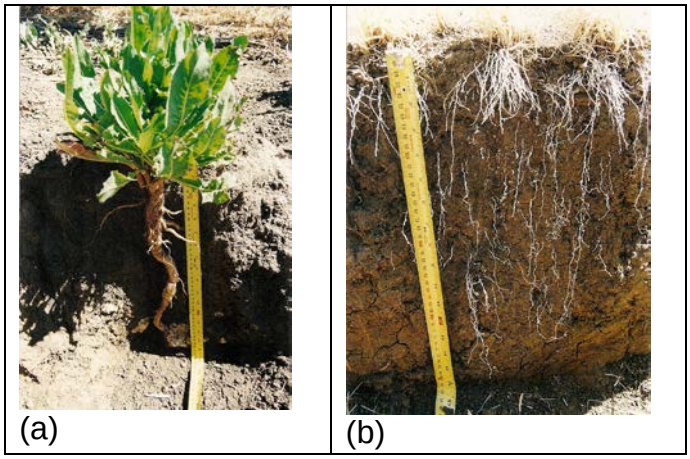


Figure 1. Differences in root distribution between (a) chicory and (b) perennial grasses (ryegrass and cocksfoot). (Proffitt 2000).

Soil water content was measured at various depths within the vine rows. Figure 2a shows that within the first year of establishment, the overall effect of planting a cover crop was a reduction in the amount of available soil water (0-140 cm depth) to the vines. This reduction was attributed to the competition for water by the cover crops, with chicory being more competitive than the grasses due to its more extensive rooting distribution. Figure 2b shows that the vines responded by extracting more water from depths greater than 20 cm and in particular, below 60 cm depth.

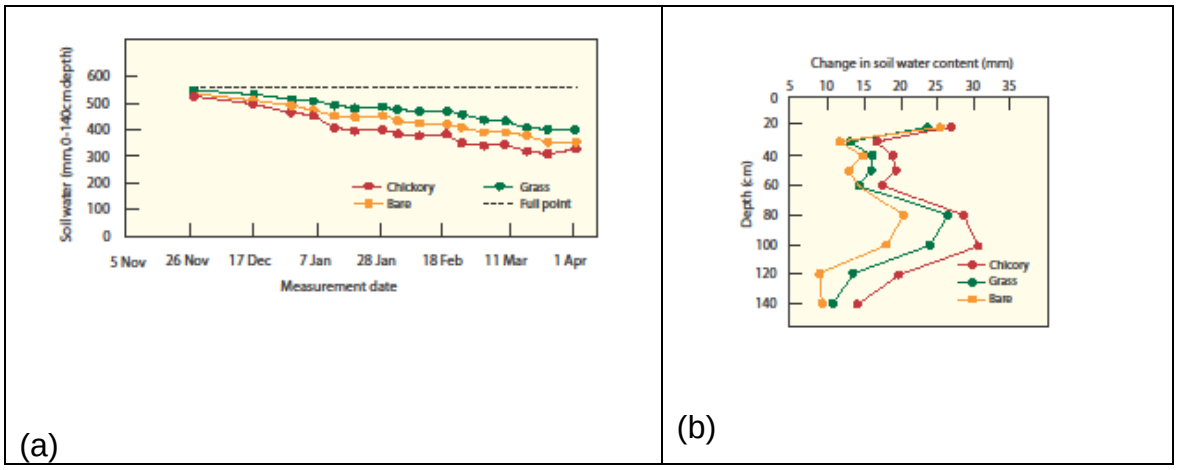


Figure 2. (a) Total soil water content (0-140 cm depth) and (b) change in soil water content with depth (0 to 140 cm) in vine rows with no cover crop in the mid-row area compared with perennial grass and chicory cover crops during the 1997/98 growing season in a Cabernet Sauvignon vineyard, Coonawarra, South Australia (Proffitt 2000).

A number of vine responses to changes in soil water availability during the first season are presented in Table 1. Where cover crops were grown, there was a slight reduction in canopy surface area and pruning weights (indices of vegetative growth) which resulted in a more open canopy as demonstrated through improved bunch exposure to sunlight. The reduction in bunch shading resulted in earlier berry ripening and an improvement in juice colour. In this study, cover crop species had little effect on vine response. The slight reduction in vegetative growth by growing cover crops was thought to be a consequence of the vines having to extract water from greater depths.

Table 1. The effect of mid-row cover crops (sown at a width of 1.5 m) on canopy surface area, pruning weight, bunch exposure, berry juice colour (measured at 13° baumé) and time taken to reach 13° baumé during the 1997/98 growing season in a Cabernet Sauvignon vineyard, Coonawarra, South Australia (Proffitt 2000).

Practice	Canopy surface area (m^2)	Pruning weight (kg)	Bunch exposure (umol/m^2/s)	Berry juice colour at 13° baumé (mg/g berry wt)	Difference in time (days) taken to reach 13° baumé
Bare mid-row	28.1	1.44	211	2.1	+7
Grass cover crop	25.5	1.31	226	2.3	-7
Chicory cover crop	26.2	1.36	225	2.3	-7

Case study 2

Caspari et al. (1997) also demonstrated that perennial ryegrass and chicory directly competed for soil moisture during spring shoot growth. Working with Sauvignon Blanc in Marlborough, New Zealand, they showed that there was greater soil water extraction where cover crops were grown compared to a bare soil regime. This resulted in a 20-80% reduction in vine vegetative growth (Figure 3). While crop yield was generally not affected by growing cover crops, the concentration of soluble solids in berries was generally higher from vines where a cover crop had been sown. This was attributed to the more open canopy due to reduced shoot growth.

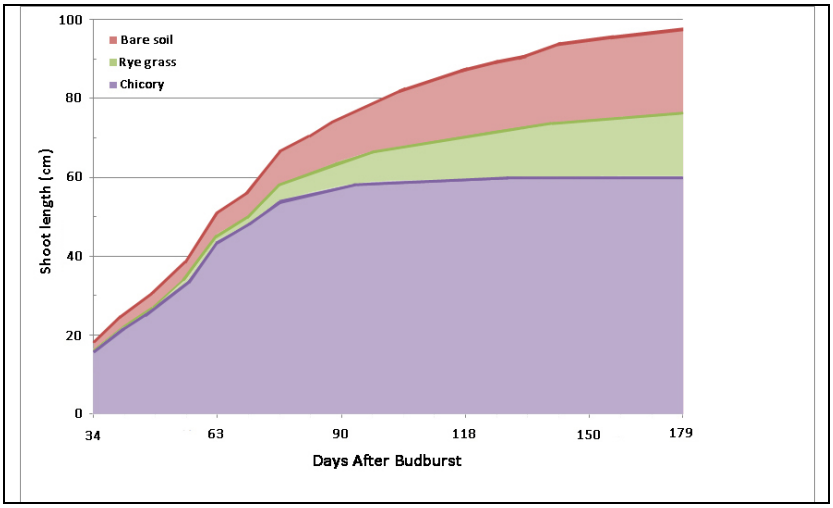


Figure 3. Shoot length (cm) of Sauvignon Blanc vines in a Marlborough, New Zealand vineyard with bare soil, perennial ryegrass and chicory cover crops during the 1994/95 growing season (Caspari et al. 1997).

Case study 3

Penfold et al. (2006) compared the effects of five different cover crop species on the performance of Shiraz vines grown in the Clare Valley, South Australia. The species consisted of a triticale (a cereal), a regenerating sward of clover and ryegrass, a perennial ryegrass/fescue mix, chicory, and a range of broadleaf weeds which were later eradicated by applying herbicide (the control practice). The perennial ryegrass/fescue mix behaved similarly to chicory with respect to soil water extractability and triticale (cereal) was relatively ineffective in accessing soil water at depth (Figure 4).

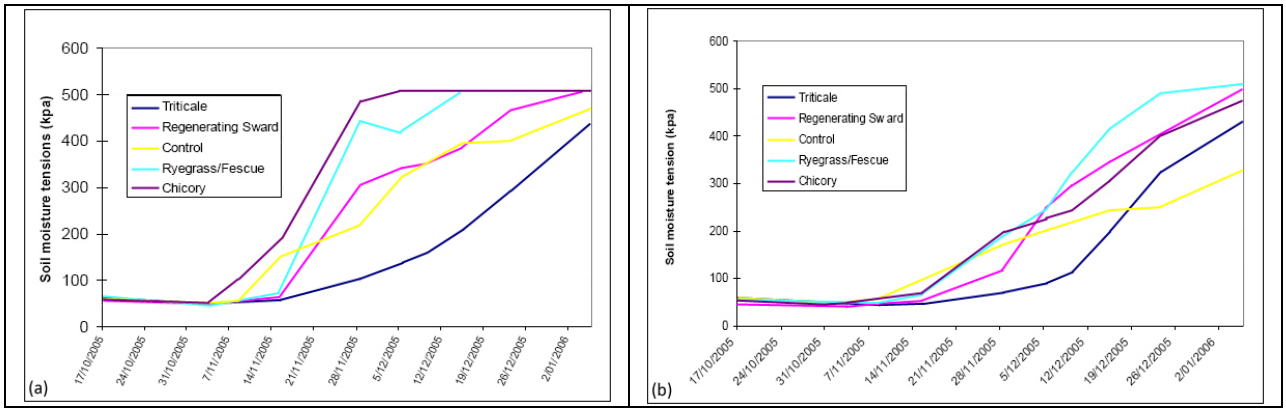


Figure 4. Change in soil moisture tensions at (a) 30 cm and (b) 60 cm soil depth within the mid-row of five cover crop treatments in a Clare Valley vineyard, South Australia (Penfold et al. 2006).

There were strong correlations between cover crop species, crop yield and canopy characteristics (Figure 5). Crop yields and leaf area index were lower where clover/ryegrass, chicory and perennial grasses were grown compared to where triticale and volunteer weeds were grown. This effect can be attributed to the differences in soil water extractability shown in Figure 4. The reduction in crop yield was due to a reduction in berry size which was considered to be a positive result from a fruit quality perspective.

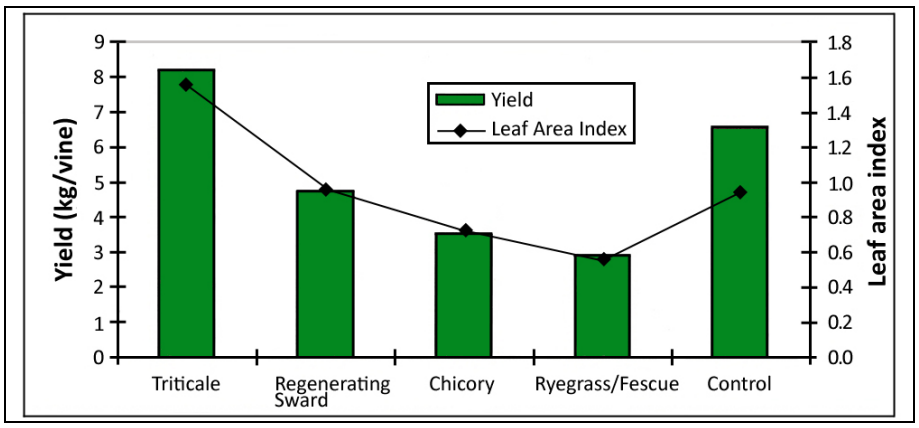


Figure 5. The effect of cover crop species on crop yield and leaf area index on Shiraz vines grown in the Clare Valley, South Australia (Penfold et al. 2006).

3. Australian native species as potential cover crops

In recent years there has been interest in the use of native plant species as potential vineyard cover crops. One of the main reasons for this is because they provide a habitat for beneficial invertebrates and have a greater capability of suppressing weeds than the majority of exotic plant species. The native grass genus which appear to be the most suitable for use as cover crops in vineyards located in medium to high rainfall regions include Austrodanthonia (wallaby grass), Microlaena (weeping grass) and Dicanthium (Queensland blue grass). For drier, hotter inland regions, Atriplex (saltbush) appears to be a suitable native cover crop alternative.

Penfold (2010 a,b,c) has trialled a number of native species in various locations within south eastern Australia. Three species were successfully established, these being wallaby grass (*Austrodanthonia richardsonii*), creeping saltbush (*Atriplex semibaccata*) and ruby saltbush (*Enchylaena tomentose*). There were differences in soil water extractability at depth between the

conventional cereal crop (barley) (Figure 6a) and two of these species; wallaby grass (Figure 6b) and saltbush (Figure 6c). At Nuriootpa in the Barossa Valley, South Australia, measurements taken within the vine row showed that soil moisture tensions at 40 cm depth reached approximately 400 kPa a month earlier where saltbush was grown compared with where barley and wallaby grass were grown. At deeper depths (70 cm), the soil dried to 400 kPa about a week earlier where the saltbush was grown compared to the wallaby grass, and about a month earlier compared to where the barley was grown. At 100 cm depth, soil moisture tensions of 500 kPa were achieved at about the same time (mid January) for each cover crop species. While rainfall and irrigation inputs reached depths of 15, 40 and 70 cm depths, they did not reach 100 cm depth.

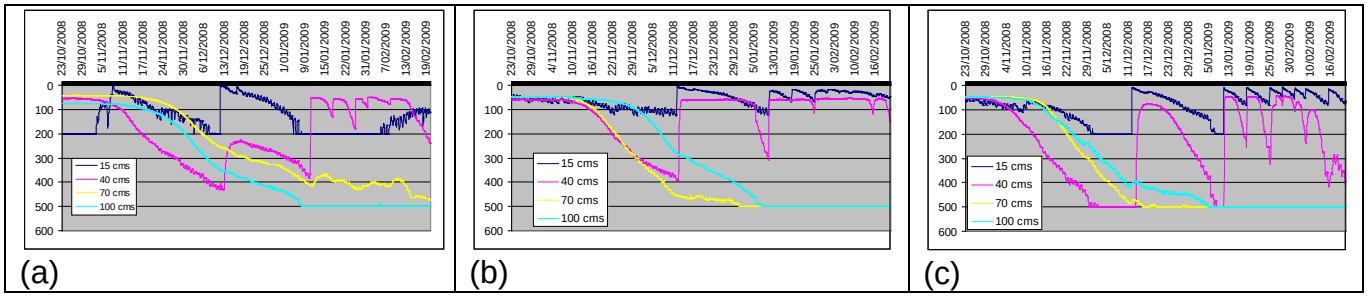


Figure 6. Soil water tensions (kPa) at 15, 40, 70 and 100 cm soil depths within the vine row of three cover crop treatments (a) barley, (b) wallaby grass, and (c) saltbush grown in a Shiraz vineyard at Nuriootpa, Barossa Valley, South Australia (Penfold 2010a).

Although their competitive nature may make native species potentially suitable for controlling vegetative growth, the cooler, wetter climatic conditions that are generally characteristic of this problem may make them difficult to become established. Penfold (2010a) concluded that to fully appreciate the potential effects of native species on vine performance, further trials need to be carried out across a greater range of climatic conditions.

4. Selecting the appropriate cover crop

The range of cover crop species available to grape growers is extensive. They are generally described as either annual (ie. those that complete their growth cycle within one year and set seed in spring before senescence and regenerate from seed the following autumn) or perennial (ie. those that survive from one season to the next, thereby becoming a permanent sward). Cover cropping does not necessarily involve the introduction of new species into the vineyard and floor management may be as simple as allowing existing (or volunteer) plants to grow (eg. introduced weeds and indigenous flora), followed by mowing, rolling or strategic herbicide applications to control their growth. A further consideration is whether to establish a monoculture or a diverse sward. Diverse swards generally offer a number of advantages associated with improved invertebrate biodiversity within the vineyard.

Cover crop selection for vineyards should be based on the desired outcomes, including consideration of the possible negative impacts of certain plant species and any site characteristics that will influence cover crop establishment. Growers should also be careful to select species that will not harbour pests or pose a problem if they need to be removed. In some cases, vineyard conditions such as saline soils will limit options with regard to what species can be grown.

Growth characteristics

The growth habit of a cover crop species can have a considerable influence on the volume of water extracted and the timing that this takes place. Demand for soil water by annual winter cover crops

typically peaks before budburst. In comparison, most perennial cover crops have an increased demand for water during late spring which coincides with grapevine flowering and fruit set. If the goal is to reduce soil moisture reserves prior to grapevine spring growth, then the use of winter annuals would be appropriate. However, if the goal is to reduce soil moisture reserves throughout the whole growing season in an attempt to control vine growth over a longer period of time, then perennial cover crops/permanent swards would be more appropriate.

Root systems

The soil depth and volume that a cover crop root system is capable of exploiting is a key factor that will determine whether the desired reduction in vine vegetative growth is achieved or not. Both the root length and the architecture (eg. deep or shallow, fibrous or taproot) play a significant role with regard to their competitive nature. It is generally accepted that fibrous, shallow rooting plants are not as effective at competing for soil moisture and nutrients as plants with root systems that can access deeper soil horizons. Annuals need to establish their root system each year following seeding, whereas perennials, once established, are able to continually develop their root systems, thereby potentially increasing the soil depth and volume from which they can source water and nutrients.

Fescue and phalaris perennial grasses have deep fibrous root systems which are capable of growing to soil depths greater than 60 cm. These, in combination with ryegrass and/or cocksfoot which have dense fibrous root masses predominantly in the upper 30 cm of soil, ensure that large volumes of soil water are accessed and extracted. Where the soil nutrient status is low, perennial grasses should be mixed with long season pasture legumes.

Forage species such as chicory and lucerne which have root systems capable of penetrating lower soil horizons are highly suitable, particularly where there is a need to lower the height of an underlying water table. However, care is required since they can be too successful in extracting soil water particularly in relatively dry years, with the result that vine shoot growth and possibly yield may be compromised.

Clover species vary greatly, with some having a taproot up to 100 cm in length supported by fibrous laterals, while others have a shallow rooting system.

Native plant species such as wallaby grass and saltbush have root length densities greater than most cereals which make them suitable competitors for water and nutrients provided that they can be established successfully.

Cereals such as triticale generally have shallow fibrous root systems located in the upper 20-30 cm of soil and are therefore generally not suitable for deep water extraction.

Nutrient contribution

In many vineyards, the mid-row area accounts for 50-60% of the vineyard floor area. The amount of nutrient available from this area will depend on the degree of vine root activity extending into the mid-row and the species of cover crop being grown. If there is little root activity due to a soil restriction (eg. compaction), then the nutrient contribution to vine growth will be minimal.

The nutritional contribution by cover crops varies and is classified according to the carbon to nitrogen (C:N) ratio in plants: high (> 30), moderate (30 to 20) and low (<20) (Madge 2005). As the C:N ratio decreases, the available N following decomposition of the organic matter increases and provides more soil N for plant growth through mineralisation. Cover crops with C:N ratios greater than 30 will result in a consumption of soil N by micro-organisms as they break down the organic material. Where vine vigour is an issue, the preferred cover crop species are those with

high C:N ratios (eg. cereals, perennial ryegrass, fescue and woody plants, or a combination of these).

5. Floor management practices

Following the selection of one or more cover crop species to suit the environmental and site characteristics of the vineyard, it is important to consider how they will be established and managed to ensure that their growth and subsequent effects on vine performance meet the desired outcomes.

Cover crop width

A number of studies have shown that cover crop width influences the degree to which soil dries at depth through plant use, which in turn, influences vine vegetative growth. Generally, the greater the amount of mid-row cover, the greater the amount of water extracted and the greater the potential effect on vine performance. In regions where ground water is saline (eg. the Great Southern in Western Australia) this effect is seen as a management tool to not only control vine vigour, but also to control the height of the water table.

McDonald et al. (2010) investigated the effect of cover crop (ryegrass) width (0, 0.8, 1.6, and 2.4 m corresponding to 0, 33, 67 and 100% mid-row cover) on water use and vine performance over three consecutive seasons in a 7 year old Shiraz vineyard at Frankland in the Great Southern, Western Australia. Table 2 shows that there was an inverse relationship between shoot length and cover crop width, with shoots from vines associated with greater mid-row cover (67 and 100%) being 20-25% shorter than those from vines associated with less cover. This result was attributed to a greater depletion of soil moisture within the mid-row at a soil depth of 60 cm. It was also observed that responses to vegetative growth were seasonally dependent. Over the three seasons, the annual rainfall at the vineyard site varied and impacted on the potential soil water recharge, and hence the time taken from budburst to deplete soil moisture to a tension of 60 kPa at 60 cm depth.

Table 2. The effect of cover crop width on vine shoot growth during the 2008 season (McDonald et al. 2010).

Cover crop width (m)	Shoot length (mm)					Overall growth (%)
	(5/10/07)	(26/10/07)	(9/11/07)	(23/11/07)	(1/12/07)	
0 (bare soil)	176[a]	500[a]	676[a]	881[a]	989[a]	466[b]
0.8	130[b]	404[b]	558[b]	743[b]	788[b]	520[b]
1.6	133[b]	382[b]	534[b]	645[b]	701[b]	431[ab]
2.4	160[a]	422[b]	560[b]	674[b]	724[b]	356[a]

Values followed by the same letter for the same measurement date are not significantly different ($p = 0.05$).

Tesic et al. (2007) also investigated the effect of cover crop width (full cover vs conventional partial cover). Their study focussed on Chardonnay over three seasons in two climatically different regions within New South Wales; Wagga Wagga which represents a hot, semi-arid climate and Tumbarumba which represents a mild, semi-humid climate. For both regions, the rate of shoot growth and final pruning weights were significantly ($p < 0.05$) reduced by growing cover crops, with the greatest reduction being observed under the full cover treatment. The decrease in shoot growth was greater at Wagga Wagga which was attributed to a combination of higher evaporative losses and 60% less seasonal rainfall. In other words, the difference in climate had the effect of exacerbating the influence cover crop growth had on depleting an already relatively dry soil profile, thereby imposing a greater soil water deficit for vine growth.

The capacity to control the degree of cover crop impact on vine vigour by managing the width of cover crop provides growers with a simple tool to control vine growth and adapt to seasonal conditions. In years of high winter/spring rainfall, a full-width cover should be allowed to develop. Conversely, in years where rainfall is low, a narrow-width cover should be used. If frost is a potential issue, narrowing the width of the cover crop will optimise the area of bare soil under vine, thereby providing a heat bank to reduce the risk of vine damage.

Time of sowing

Any cover crop that has an active growth phase occurring before or overlapping with shoot growth in spring will potentially have an impact on vine vegetative growth. The time of sowing is important, particularly for annuals that can be established either in autumn (winter annuals) or spring (summer annuals). Sowing close to the 'break of season' (eg. late autumn) when the soil is moist and remains warm will enhance germination rates and early vigour in the cover crop, thereby maximising the potential competition for water and nutrients. Sowing too early increases the risk of a 'false break' whereby seeds will germinate and then die due to lack of moisture.

Seeding time also influences the duration of competition that occurs between grapevines and cover crops for soil moisture and at what grapevine phenological stage the competition occurs. For example, legume cover crops (both pasture and grain species) actively grow for at least 20 weeks if sown at the autumn break and maximum water use would occur in spring which coincides with active vine shoot growth. The timing of cover crop establishment can therefore determine the potential overlap for peak water demand by the vine.

Controlling growth

Cover crop growth can be manipulated by mowing, rolling, cultivation and/or herbicide spraying. In this context it is important to have a management plan that incorporates options for wet and dry seasons.

Where excessive vine vigour is considered an issue in established vineyards, cover crop growth should be maintained until seed-set to maximise the competition for water and nutrients. However, growth should be controlled earlier if the soil starts to dry. Soil moisture monitoring equipment can provide this information. Cultivation, when compared to the benefits associated with mowing or rolling a cover crop, is generally not recommended due to the potential soil degradation issues that this practice imparts.

When mowing, consideration should be given to side-throwing the material undervine since this 'mulch' provides a number of soil health and nutritional benefits, as well as helping to conserve soil moisture and suppressing weed growth. However, when mowing at seed-set, preference should be given to keeping the material within the mid-row area in order to retain sufficient seed to establish the sward in the following season.

Where vine vigour is a problem, a further consideration is that side-throwing material will directly supply N to the vine which may have the undesired effect of enhancing vegetative growth. For example, a cereal crop producing 5 t/ha of biomass will contain approximately 75 kg/ha of N. Assuming the undervine area accounts for 50% of the floor area, then the equivalent of 150 kg/ha of N will be applied to vines. However, only about 20% of this N will be available in the first year, with the remainder becoming lost as volatile ammonia or becoming bound to soil organic matter and released slowly over several years as it is mineralised by soil microbes.

Penfold (2003) outlines a simple protocol for calculating the approximate amount of N provided by a cover crop:

- Select four representative mid-row sites within the vineyard.
- From each site, select an area of about 0.25 x 0.25 m, cut at mower-height the above-ground material and oven-dry at 60^{o}C (this is referred to as the biomass).
- Weigh the dry material and calculate the amount of biomass (kg/ha).
- Assume non-legume species contain about 1.5% N while legumes contain about 2.5% N. If the cover crop consists mainly of non-legumes, multiply the dry weight (kg/ha) by 0.015 and for legumes multiply by 0.025. This provides the amount of plant N/ha.

6. Evaluating the outcome

The use of competitive cover crops to manipulate overall vine performance needs to be evaluated over a number of seasons. In some cases vine performance measures may be improved in the first year of establishing the cover crop, but in general it can take at least two to three seasons for the sward to become fully effective in competing for water and nutrients. Dry et al. (2005) propose that the overall performance of vines undergoing management changes should be evaluated by 'benchmarking' them against 'reference' vines (ie. vines which meet the desired crop yield and fruit quality specifications).

Soil moisture status

Soil moisture status (in the form of either soil water suction or volumetric soil water content) should be measured routinely both within the vine row and within the mid-row area. This is a fundamental measure which will demonstrate the effectiveness (or otherwise) of the cover crop in reducing the amount of available water to the vines. The correct installation and positioning of such equipment is important if the data is to be representative of the vineyard conditions.

- There should be at least one measuring site per soil type, with 3 or more measurement depths per site.
- The greater the spatial variation in soil characteristics and vine performance, the greater the number of measuring sites required.
- The sensors should be positioned in relation to the root distribution of the cover crop(s) and vines being grown. Soil pits will need to be dug in order to determine the distribution of the various root systems within the soil profile.
- One sensor should be positioned close to the soil surface within the zone where the majority of the roots occur (eg. about 20-30 cm depth).
- A second sensor should be positioned lower in the soil profile (eg. about 50-60 cm depth).
- A third sensor should be positioned close to the base of the root zone.

Vegetative growth, crop yield and berry composition

Neither 'low' or 'high' vigour shoot growth are necessarily undesirable; it is only when shoots have either insufficient vigour to maintain and ripen a reasonable quantity of fruit or excessive vigour where growth competes with the ripening fruit for resources and/or creates excessive shading of both leaves and fruit that there are undesirable consequences. Compared with low vigour shoots, high vigour shoots are generally longer, thicker, flatter in appearance and have longer internodes, larger leaves and more lateral shoot growth. In some cases they do not lignify fully after leaf fall. Lateral shoots will often continue to grow after main shoot growth has either

slowed down or ceased. Excessive vegetative growth usually results in shaded canopy conditions and poor bunch exposure to sunlight.

Bunch and berry numbers and size should be monitored throughout the season and final yield, expressed on either a vine or area basis, determined at harvest. This is important since it is possible that the effectiveness of the cover crops in competing for water and nutrients will compromise crop yield. However, this is likely to be noticed and acted upon early in the season if soil moisture and/or vegetative growth measures are regularly acquired.

The desired ripening pattern for fruit is one where the change in sugar concentration and other flavour components immediately after veraison is rapid. This is likely to result in more favourable berry quality attributes than a ripening pattern where changes are relatively slow (Iland et al. 2011). Therefore, regular measurements of berry juice ^{o}Brix, pH and titratable acidity from a time just after veraison to harvest are required. At harvest, seeds should be fully lignified and berry juice should meet the desired sugar and acidity parameters as well as the desired flavour profile.

Table 3 provides examples of vine growth and canopy density descriptors that are easily assessed in the vineyard. It is recommended that at least 3 sites within the block of vines are assessed in order to account for spatial variability in vine performance. The assessment sites can be an individual vine, a panel of vines or vines within a defined length of vine row (eg. 20 m). The assessments should be performed at veraison and close to harvest.

Quantitative measures commonly used to assess the balance between vegetative and fruit growth include the ratio of total leaf area to fruit weight (m^2/kg) and the ratio of fruit weight to pruning weight (kg/kg).

Table 3. Descriptors of vine growth and canopy density that should be assessed in the vineyard to evaluate the effectiveness of cover crops in controlling vegetative growth (adapted Iland et al. 2011).

Descriptor	Descriptor
Main shoot	**Canopy light condition**
average shoot length (untrimmed) cm	heavily shaded
average internode length (nodes 6-7) cm	partly shaded
number of leaves on average shoot	partly exposed (dappled light)
% of shoots with growing tips	fully exposed
Shoot lignification (main shoots)	**Average number of leaves in front of a bunch**
zero-little	>3 leaves
low	3 leaves
moderate	2 leaves
extensive	1 leaf
full	no leaves
Lateral shoot growth	**% of bunches exposed to sunlight**
low	100-80
moderate	60-80
extensive	40-60
	20-40
Leaf condition	<20
dark green, shiny, healthy	
pale green, wilting	**Dates**
basal leaves yellowing from stress	date of veraison
% leaves remaining	date of reaching set ^{o}Brix
other symptoms (nutrient, wind, salt)	date of harvest

Costs

The establishment and management of a cover crop is a financial cost. Establishment costs generally include the purchase and sowing of the seed and fertilizer, while management costs generally include the purchase and application of fertilizer if required and operations associated with controlling growth (eg. mowing, rolling, herbicide or cultivation). The sowing of an annual cover crop can become a significant cost while the management of a permanent sward is cheaper since it does not require to be established each year. In either case, the costs associated with cover cropping need to be evaluated in relation to the potential benefits in financial returns through improvements in fruit (and possibly wine) quality and vineyard sustainability through improved soil health and increased biodiversity. The costs should also be evaluated in relation to current soil management practices which maybe more expensive.

Final outcome

If the evaluation shows that the use of cover drops has been successful in reducing vegetative growth, then consideration needs to be given to on-going management practices such as bud numbers retained at pruning, crop yield, canopy management/trellis system, and irrigation and nutrition practices in relation to the smaller canopy.

If the evaluation does not meet the desired outcomes, then alternative management strategies need to considered (which include those listed above), as well as a re-assessment of the cover crop species selected and/or management practices.

7. Summary points

In grape growing regions, or indeed within areas of a vineyard where excessive shoot growth prevails, certain cover crop species can be used to compete directly with vines for soil water and nutrients, thereby increasing light and airflow penetration into the canopy and hastening grape maturation. These positive effects have been shown to manifest themselves in superior wine quality.

Key points for consideration with respect to the selection, establishment, management and evaluation of a cover crop for this purpose include the following:

Species selection

- Diverse swards, as opposed to monocultures, should improve vineyard biodiversity.
- Perennial species should be more effective than annual species.
- Root length and distribution characteristics (ie. deep or shallow, fibrous or taproot) are critically important to provide a competitive effect. Plants with root systems that can access deep soil horizons are required. A combination of shallow and deep rooting perennial grass species generally perform very effectively.
- Care is required if using highly competitive forage species such as chicory and lucerne as they are highly competitive in extracting soil water and result in compromised vine growth and crop yield. They are effective in lowering water tables where this is required.
- The nitrogen contribution on an area basis (eg. N/ha) should be calculated and considered in the species selection process. The preferred cover crop species are those with high C:N ratios (eg. cereals, perennial ryegrass, fescue and woody plants or a combination of these) as these species result in a consumption of soil N by micro-organisms as they break down the organic material.
- Native grasses and saltbush appear to be alternative species worthy of consideration but they may be difficult to establish in cool, wet environments.

Establishment

- Vines need to have a proportion of their root system within the mid-row area in order for cover crops to have a major influence on vegetative growth. If they are restricted to the vine row, then the use of cover crops to control vegetative growth is likely to be ineffective. This should be assessed prior to establishing the cover crop.
- The greater the sowing width, the greater the potential effect on vine performance. The width of cover crop should be used to manage vine growth and adapt to seasonal conditions.
- The timing of cover crop establishment and growth influences the duration of soil and nutrient competition and at what phenological stage this competition occurs. Sowing close to the break of season (eg. April/May) maximises the potential effect.

Management

- Cover crop growth should be maintained until seed-set to maximise the competitive effect. Growth should be controlled earlier if the soil starts to become too dry. Therefore, it is important to have a management plan which provides options for manipulating cover crop growth in wet and dry seasons.
- The use of soil moisture monitoring equipment is recommended to ensure that soils do not become overly dry.
- Mowing, rolling and/or herbicide spraying are the preferred options for controlling cover crop growth rather than cultivation.
- Side-throwing early mown material will provide an undervine mulch which provides soil health and nutritional benefits, as well as helping to conserve soil moisture and suppressing weed growth. Preference should be given to keeping material mown close to seed-set within the mid-row area in order to retain sufficient seed to establish a sward in the following season. This also ensures that there is a reduction in the direct supply of N to the vines.

Evaluation

- The cover crop program needs to be evaluated over a number of seasons as it is likely to take at least two to three seasons for the sward to become fully effective.
- The competitive nature of the cover crops should be evaluated by continuously measuring soil water status both within the vine row and the mid-row area.
- Vine responses should be evaluated by assessing vegetative growth and canopy density characteristics, crop yield and berry compositional attributes.
- Benchmarking vine responses to changes in floor management practices provides a useful way of evaluating whether the changes have been successful.
- If the desired outcomes have been achieved, an assessment of the on-going management practices should be made in relation to the smaller canopy.
- If the desired outcomes have not been achieved, alternative management strategies should be considered and the cover crop species selection and/or management practices should be re-assessed.

The decision-tree shows the steps to consider when using cover crops to manipulate the growth of overly vigorous vines.



Further resources

General information on cover cropping can be found under the Innovators Network on the GWRDC website: http://www.gwrdc.com.au/site/page.cfm?u=129
In addition, a decision support tool for the selection of cover crops can be found at the following website: http://www.covercropfinder.com.au/tool.php?id=1

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Adoptable Outcome 7. Using cover crops to control vigorous vine growth

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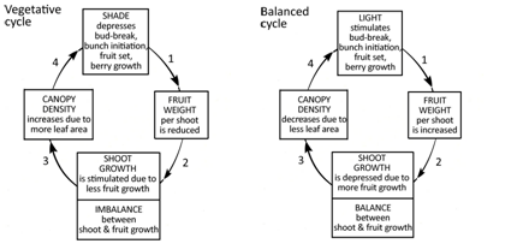
Optimising Industry Returns for Existing Soil and Water Research

Using cover crops to control vigorous vine growth

Presenter(s)

1. Introduction

High vigour – the vicious cycle



Smart and Robinson (1991)

1. Introduction

The effects of shaded canopy conditions

- Less solar radiation
- Altered ratio of short : longwave radiation
- Lower leaf and bunch temperature
- Greater humidity
- Reduction in the amount of available carbon dioxide
- Reduced photosynthetic and metabolic activity of the vine

1. Introduction

The effects of shaded canopy conditions

- Lower crop yields
  - Reduced bud fruitfulness
  - Increased level of bud and inflorescence necrosis
- Higher risk of disease
  - Botrytis bunch rot (*Botrytis cinerea*)
- Poorer fruit quality
  - Delayed ripening
  - Undesirable berry compositional properties

1. Introduction

Effect of shade on grape composition and potential wine quality

- ↓ sugar levels (dilution)
- ↓ tartaric acid (dilution)
- ↓ phenols and anthocyanins in red wine
- ↓ monoterpene flavour compounds
- ↓ varietal or fruit character on the nose and palate
- ↑ juice and wine potassium and pH
- ↑ malic acid (lower berry temperatures)
- ↑ herbaceous or grassy characteristics in the wine
- ↑ incidence of botrytis bunch rot
  (off-flavours, premature aging of wine)

1. Introduction

Cabernet Sauvignon, Margaret River (Wilkinson et al. 2006)

Vigour class	Shoot length (cm)	Light interception at fruit zone (% PAR)	Light interception by canopy (% PAR)	Berry juice (°Brix)	Wine IMBP concentration (ng/L)
High vigour	139	6.6	4.1	24.1	32
Low vigour	93	16.2	31.4	23.7	10

PAR - Photosynthetically Active Radiation
IMBP - Isobutylmethoxypyrazine

- High vigour vines had greater shoot length, higher canopy density, and more shaded leaves and fruit
- Resulting wines (fruit at similar maturity) had greater concentration of IMBP

1. Introduction

Unbalanced vines – poor fruit exposure



1. Introduction

Balanced vines – good fruit exposure





1. Introduction

Cover crops

- What is the best cover crop to plant?
  There is no single 'best' cover crop for all vineyards!
- The potential advantages and disadvantages of a cover crop differ from vineyard to vineyard depending on…
  - Climate
  - Soil type and fertility
  - Irrigation system
  - Age of vines
  - Frost risk
  - Pest and disease pressure
  - Erosion risk
  - Establishment and management costs

1. Introduction

Cover crops – their potential benefits

- Improved soil physical, chemical and biological properties
  - Water infiltration, soil structure, organic matter, micro / macro-organism activity
- Suppression of weed growth
- Minimal soil loss through wind and water erosion
- Moderated soil temperatures
- Improved invertebrate biodiversity
- Reduced vegetative growth
  - Competition for water and nutrients

2. The competitive nature of cover crops

Success of cover crops in controlling vegetative growth depends on……

- Environmental conditions
  Seasonal variability
- Cover crop species
  Growth characteristics
- Floor management practices
  Establishment and management of the cover crop
- Vine root distribution
  Need to be within mid-row area as well as within vine row

2. The competitive nature of cover crops

Vegetative growth

- Competition between cover crops and vines for soil water can result in significant decrease in vegetative growth (10-70% commonly quoted)
  - Rate of shoot growth, canopy density, pruning weight
- Result is a smaller, easier to manage canopy often with reduced operating costs and improved fruit quality

2. The competitive nature of cover crops

Soil water extraction

- Direct competition with vines for water and nutrients
  - Extraction of water (particularly in upper 30-40 cm soil layer) prior to rapid shoot growth in spring
- Accelerates the drying of the soil profile so that deficit irrigation strategies can be implemented
  - Regulated Deficit Irrigation (RDI)
  - Partial Rootzone Drying (PRD)

2. The competitive nature of cover crops

Case study 1 (Proffitt 2000)

- Coonawarra, South Australia
- 15 year old Cabernet Sauvignon
- Three mid-row practices
  - Bare (herbicide)
  - Cocksfoot / ryegrass (3:1) sown 1.5 m wide
  - Chicory sown 1.5 m wide

2. The competitive nature of cover crops



Bare - herbicide



Perennial grass



Chicory

2. The competitive nature of cover crops



Chicory

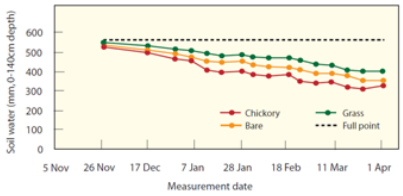


Ryegrass / Cocksfoot

- Taproot of chicory grew to 40 cm in 1st season, 60 cm in 2nd season
- Fibrous roots of grasses grew to 20 cm in 1st season, 40 cm in 2nd season

2. The competitive nature of cover crops

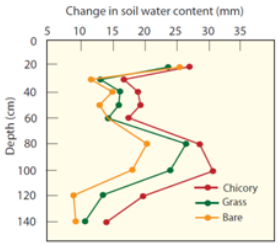
Soil water content (0-140 cm) measured within vine rows



- Within one year there was a reduction in available water (0-140 cm depth)
- Chicory more competitive than the grasses due to extensive root system

2. The competitive nature of cover crops

Change in soil water content with depth (0-140 cm)



- Vines responded by extracting more water from depths greater than 20 cm and in particular, below 60 cm depth

2. The competitive nature of cover crops

First year response to cover crops

Practice	Canopy surface area (m^2)	Pruning weight (kg)	Bunch exposure ($umol/m^2/s$)	Berry juice colour at 13° baumé (mg/g berry wt)	Difference in time taken to reach 13° baumé (days)
Bare mid-row	28.1	1.44	211	2.1	+7
Grass cover crop	25.5	1.31	226	2.3	-7
Chicory cover crop	26.2	1.36	225	2.3	-7

- Slight reduction in canopy surface area and pruning weights
- More open canopy and improved bunch exposure to sunlight
- Earlier berry ripening
- Improved berry juice colour
- No difference in response between cover crop species

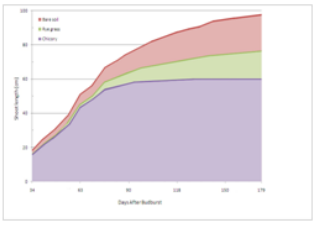
2. The competitive nature of cover crops

Case study 2 (Caspari et al. 1997)

- Marlborough, New Zealand
- Sauvignon Blanc
- Three mid-row practices
  - Bare (herbicide)
  - Ryegrass
  - Chicory

2. The competitive nature of cover crops

Shoot length during the growing season



- Greater soil water extraction where cover crops were grown
- This resulted in a 20-80% reduction in vegetative growth and higher soluble solids in berries due to more open canopy

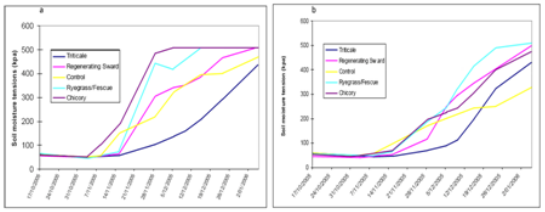
2. The competitive nature of cover crops

Case study 3 (Penfold et al. 2006)

- Clare Valley, South Australia
- Shiraz
- Five mid-row practices
  - Weeds followed by herbicide (bare)
  - Triticale (cereal)
  - Clover / ryegrass mix (regenerating sward)
  - Perennial ryegrass / fescue mix
  - Chicory

2. The competitive nature of cover crops

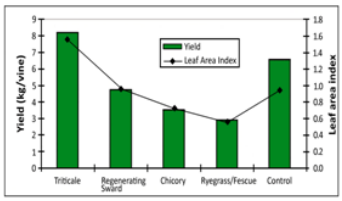
Soil moisture tensions at (a) 30 cm and (b) 60 cm soil depth within mid-row



- Ryegrass / fescue mix behaved similarly to chicory in soil water extractability
- Triticale (cereal) was ineffective in extracting water at depths 30 and 60 cm

2. The competitive nature of cover crops

Effect of cover crop species on crop yield and leaf area index (LAI)



- Crop yield and LAI were lower for clover / ryegrass, chicory and perennial grasses compared to triticale and weed / herbicide practices
- Attributed to differences in soil water extractability between plant species

3. Australian native species as potential cover crops

Potential benefits

- Provide good habitat for beneficial invertebrates
- High capability for suppressing weeds
- Persistent
- Competitive for water and nutrients

BUT, potentially difficult to establish in cool, wet climatic conditions – need to assess performance across a greater range of environments

3. Australian native species as potential cover crops

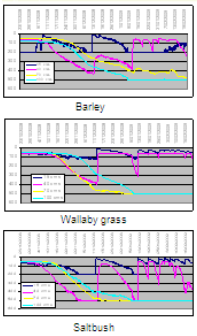
Possible options within the native grass genus for medium to high rainfall regions include…..

- Wallaby grass (*Austrodanthonia*)
- Weeping grass (*Microlaena*)
- Queensland blue grass (*Dicanthium*)

For drier, hotter inland regions

- Saltbush (*Atriplex*)

3. Australian native species as potential cover crops



Shiraz, Barossa Valley, South Australia (Penfold 2010a)

Changes in soil water tension at 15, 40, 70 and 100 cm soil depths within the vine row

- Saltbush dried soil to 400 kPa at 40 cm depth a month earlier than the other two cover crop species
- Saltbush dried soil to 400 kPa at 70 cm depth a week earlier than wallaby grass and a month earlier than barley

4. Selecting the appropriate cover crop

Options are extensive

- Annual vs perennial
- Introduced species vs existing volunteer species
- Monoculture vs diverse sward

Selection needs to be based on…..

- Desired outcomes (eg. soil health, soil fertility, vine vigour)
- Possible negative impacts (eg. pests, soil moisture)
- Site characteristics that influence establishment (eg. rainfall, temperature, soil type, salinity)

4. Selecting the appropriate cover crop

Growth characteristics

- Influences volume of water extracted and timing of extraction
  - Annual species – demand for water peaks before budburst
  - Perennial species – demand for water peaks in late spring which coincides with grapevine flowering / fruit set
- Perennial cover crops / permanent swards are more appropriate to control vine growth over a longer period of time

4. Selecting the appropriate cover crop

Root systems

- Soil depth and volume that cover crop root system exploits is a key factor to their effectiveness in depleting soil water reserves and controlling vegetative growth
  - Fibrous, shallow rooting plants are not as effective as those with taproots or long fibrous roots
  - Annuals need to establish root systems each year, whereas perennials continually develop their roots (greater volume and depth)

4. Selecting the appropriate cover crop

Root architecture

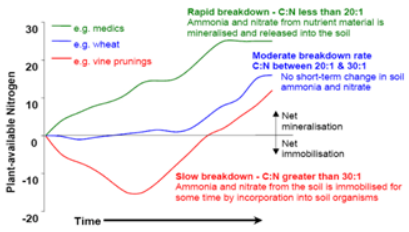
- Cereals: Generally have shallow, fibrous roots (upper 30 cm)
- Grasses:
  - Ryegrass and cocksfoot have shallow, fibrous roots (upper 30 cm)
  - Fescue and phalaris have deep, fibrous roots (60 cm+)
- Forage crops:
  - Chicory and lucerne have deep tap roots (60 cm+)
  - Highly successful in extracting water at depth - care required, particularly in dry years
- Clovers: variable root depth (species-dependent)
- Native species: (eg. wallaby grass, saltbush) have greater root length densities than most cereals

4. Selecting the appropriate cover crop

Nutrient contribution

- Nutritional contribution to vines depends on....
  - Vine root activity into mid-row
  - Cover crop species being grown
  - Area of mid-row (often occupies about 50-60% of vineyard floor)
- Nutritional contribution is classified according to carbon:nitrogen (C:N) ratio in plants
  - high (>30), moderate (30-20), low (<20)
- Consider high C:N species where there is vigorous growth
  - High consumption of soil N by micro-organisms as they break down organic material - less available to vine (eg. cereals, perennial ryegrass, fescue, woody plants)

4. Selecting the appropriate cover crop



General relationship between the carbon:nitrogen ratio (C:N) of organic matter and rate of nitrogen mineralisation (Madge 2005)

5. Floor management practices

Cover crop width



- Greater the amount of mid-row cover, the greater the competition exerted by the cover crop for soil water and potentially, the greater effect on vine performance
- Width of mid-row cover is a simple way to control vine growth and adapt to seasonal conditions
  - Full width in years of high winter / spring rainfall
  - Narrow width when rainfall is low and / or when frost is a threat

5. Floor management practices

Mown sward - clean undervine, narrow mid-row cover crop



Mown sward - grasses left undervine, wide mid-row cover crop



5. Floor management practices

Shiraz, Frankland, Great Southern, WA (McDonald et al. 2010)

Effect of cover crop (ryegrass) width on vine shoot growth

Cover crop width (m)	Shoot length (mm) (5/10/07)	(26/10/07)	(9/11/07)	(23/11/07)	(1/12/07)	Overall growth (%)
0 (bare soil)	176[a]	500[a]	676[a]	881[a]	989[a]	466[b]
0.8	130[b]	404[b]	558[b]	743[b]	788[b]	520[b]
1.6	133[b]	382[b]	534[b]	645[b]	701[b]	431[ab]
2.4	160[a]	422[b]	560[b]	674[b]	724[b]	356[a]

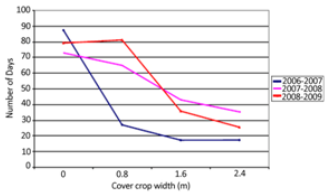
Values followed by same letter for same measurement date are not significantly different ($p = 0.05$)

- Shoots on vines associated with greater mid-row cover (1.6 and 2.4 m), were 20-25% shorter than those with less cover
- Reduced shoot growth attributed to greater depletion of soil moisture within mid-row at 60 cm soil depth

5. Floor management practices

Seasonal variability

The number of days from bud burst for different cover crop widths to dry soil to >60 kPa at 60 cm depth for three consecutive seasons (McDonald et al. 2010)

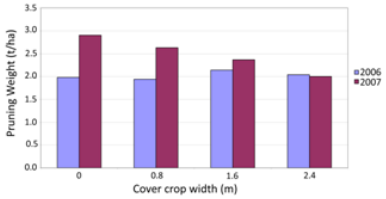


- Regardless of the season, the wider cover crop (ryegrass) widths resulted in a more rapid depletion of soil moisture within the mid-row

5. Floor management practices

Seasonal variability

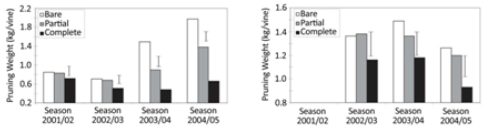
Effect of cover crop width and season (2005/06 and 2006/07) on pruning weight (McDonald et al. 2010)



- Insufficient soil moisture recharge in 2005/06 season reduced vine growth regardless of width of mid-row cover

5. Floor management practices

Chardonnay, two contrasting climates in New South Wales (Tesic et al. 2007)



Wagga Wagga: hot semi-arid climate MJT 24°C, 2050 GDD, 304 mm rainfall (October to April)

Tumbarumba: mild semi-humid climate MJT 20.1°C, 1318 GDD, 492 mm rainfall (October to April)

Vertical bars denote LSD at $p = 0.05$

- Rate of shoot growth and pruning weights were reduced by growing cover crops, with greater reduction under complete mid-row cover than with partial cover
- Response was greater at Wagga Wagga due to influence cover crop had on depleting a drier soil profile – resulted in a greater soil water deficit for vine growth

5. Floor management practices

Time of sowing

- Cover crops with active growth phase occurring before or overlapping with shoot growth in spring will potentially impact on vegetative growth
  - Sowing date will influence duration and timing of competition
  - Sowing close to 'break of season' (late Autumn) promotes early vigour of cover crop and maximises potential competition for water and nutrients
- Cover crops should not deplete soil water reserves before berry set – similar to implementing RDI
  - Potential reduction in crop yield

5. Floor management practices

Establishment considerations

- Seed bed preparation (seed size, soil tilth)
- Inoculation (legumes require inoculation)
- Time of planting (moisture, temperature)
- Seeding rate (seed size and type, weather)
- Seeding depth (seed size)
- Seeding machine (calibration)
- Pests (eg. snails, weevils, beetles, red-legged earth mite)

5. Floor management practices

Controlling growth

- Growth should be managed to minimise or increase the potential impact on vegetative growth
  - Mowing / slashing, rolling, cultivation and / or herbicide spraying
- Maintain growth until seed-set to maximise competition BUT control earlier if soil becomes too dry
  - Use soil moisture monitoring devices
- Avoid cultivation where possible
  - Soil degradation

5. Floor management practices

Controlling growth

- Side-throwing mown material provides a beneficial 'mulch' BUT will directly supply nitrogen (N) to vines
  - Could enhance vegetative growth
  - Non-legumes contain about 1.5% N
  - Legumes contain about 2.5% N

Example:
- Cereal producing 5 t/ha biomass will contain about 75 kg/ha N
- If undervine area = 50% of floor area, then equivalent of 150 kg/ha N will be applied to vines
- Only 20% of this N will be available in 1st year; remainder will become lost (volatile ammonia) or bound to soil organic matter

5. Floor management practices

Protocol for calculating approximate amount of N provided by a cover crop (Penfold 2003)

- Select 4 representative mid-row sites per vineyard block
- For each site, select an area 0.25 x 0.25 m
- Cut, at mower height, the above-ground material, oven-dry at 60°C and weigh (kg)
- Calculate the dry biomass (kg/ha)
- Multiply non-legume dry biomass material by 0.015 and legume dry biomass by 0.025 to calculate N/ha

6. Evaluating the outcome

Evaluate vine performance over 2-3 or more seasons

- Soil moisture status
  - Measure routinely within vine rows and within mid-row area
  - Use appropriate equipment and install / position correctly

Example:
- At least 1 measuring site per soil type (more if soils are very variable)
- At least 3 measurement depths per site
- Dig soil pits to determine root distribution of vines and cover crops
- Position 1st sensor close to soil surface where majority of roots occur
- Position 2nd sensor lower in profile at about 50-60 cm depth
- Position 3rd sensor close to base of root zone

6. Evaluating the outcome

- Vegetative growth
  'High' vigour shoot growth vs 'low' vigour shoot growth
  - Longer, thicker, flatter, longer internodes, larger leaves, more lateral growth
  - Poor lignification after leaf fall, lateral growth continues to grow after main shoot growth has slowed down or ceased
  - Shaded canopies and poor bunch exposure to sunlight

Quantitative measures to assess balance between vegetative and fruit growth include……
  - Total leaf area to fruit weight (m^2/kg)
  - Fruit weight to pruning weight (kg/kg)

6. Descriptors of vine growth and canopy density used in the vineyard to evaluate effectiveness of cover crops in controlling vegetative growth (adapted from Iland et al. 2011)

Descriptor	Descriptor
Main shoot	**Canopy light condition**
Average shoot length (untrimmed) cm	Heavily shaded
Average internode length (nodes 6-7) cm	Partly shaded
Number of leaves on average shoot	Partly exposed (dappled light)
% of shoots with growing tips	Fully exposed
Shoot lignification (main shoots)	**Average number of leaves in front of bunch**
Zero-little	>3 leaves
Low	3 leaves
Moderate	2 leaves
Extensive	1 leaf
Full	no leaves
Lateral shoot growth	**% of bunches exposed to sunlight**
Low	100-80%
Moderate	60-80%
Extensive	40-60%
	20-40%
Leaf condition	<20%
Dark green, shiny, healthy	
Pale green, wilting	**Dates**
Basal leaves yellowing from stress	Date of veraison
% leaves remaining	Date on reaching a certain °Brix
Other symptoms (nutrient, wind, salt)	Date of harvest

6. Evaluating the outcome

- Crop yield
  - Monitor bunch and berry numbers and size throughout season
  - Determine final yield at harvest

- Berry composition
  - Monitor juice °Brix, pH and titratable acidity from veraison to harvest
  - Desired ripening pattern (sugar concentration, flavour components) from veraison to harvest should be rapid
  - At harvest, seeds should be fully lignified and juice should meet desired sugar, acid and flavour parameters

6. Evaluating the outcome

- Costs vs returns
  - Is there a financial return through improvements in fruit and wine quality?
  - Has greater vineyard sustainability been achieved through improved health and increased biodiversity?
  - How do the costs compare with current management practices?

6. Evaluating the outcome

Final outcome
- Benchmark changes in vine performance against 'reference' vines

If evaluation shows that cover cropping has been successful:
- Review management practices in response to the smaller canopy (eg. bud numbers, crop yield, canopy management/trellis system, irrigation and nutrient programs)

If evaluation does not meet required outcomes:
- Consider other vegetative control practices (eg. those listed above)
- Re-assess selection of cover crop species and their management

7. Summary points

Species selection

- Diverse swards are likely to be better option
- Perennial species are likely to be more effective
- Deep root systems are required – combinations of shallow and deep rooting plants perform effectively
- Beware of highly competitive plants (eg. lucerne, chicory) as they could be too effective and compromise vine growth and yield
- Calculate nitrogen contribution of cover crops – consider plants with high carbon:nitrogen ratios
- Native grasses and saltbush are worthy of consideration but they can be difficult to establish in cool, wet environments

7. Summary points

Establishment

- Assess vine root distribution prior to sowing a cover crop - vines need a proportion of their root systems within mid-row area for cover crops to be effective
- Greater the sowing width, the greater the potential effect on vine growth
- Sowing early (eg. close to break of season) maximises the potential competitiveness

7. Summary points

Management

- Maintain cover crop growth until seed-set – control earlier if soil becomes dry
- Use soil moisture monitoring equipment to ensure soils do not become too dry
- Mowing, rolling and / or herbicide spraying are the preferred options for controlling growth
- Side-throw early mown material to provide a mulch
- Keep material within mid-row if mown at seed-set in order to retain seed for following season

7. Summary points

Evaluation

- Evaluate effectiveness of cover crop program over 2-3 or more seasons
- Measure soil water status in both the vine row and mid-row area
- Assess vegetative growth, canopy density, crop yield and berry composition
- Benchmark vine response with vines which meet the desired attributes
- If desired outcomes *have* been achieved, assess on-going management practices in relation to the smaller canopy
- If desired outcomes *have not* been achieved, assess alternative management strategies and re-assess the selection of cover crop species and their management

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