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Development of a low-input under-vine floor management system which improves profitability without compromising yield or quality



FINAL REPORT to
Wine Australia

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Development of a low-input under-vine floor management system which improves profitability without compromising yield or quality

Wine Australia project UA 1303

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ABSTRACT

The under-vine zone of the vineyard contains the greatest concentration of vine roots, with management directly impacting vine yield, quality and profitability. The removal of weeds involves regular use of herbicides or cultivation, neither of which is recognised as best practice soil management. This project investigated the growth of cover crops below the vine which are both beneficial to the soil and the vine while competing with or suppressing the growth of weeds. At four South Australian sites, annual pasture legume and grass cover crops generated yields and financial gross margins equivalent to or greater than the herbicide controls.

EXECUTIVE SUMMARY

The typical view of a vineyard shows the area between the vines to be covered with vegetation that is mown to prevent excessive growth, which keeps it looking respectable while reducing the loss of soil moisture. The area under the vines is maintained in a bare state with herbicides, as weeds can otherwise grow into the vine canopy while utilising soil moisture that should be available to the vines. The maintenance of this soil in a bare state is however not in line with best practice soil management, prompting a research program to develop an environmentally benign alternative system which does not result in a financial impost through reduced productivity.

Using lessons from the broadacre farming sector, field trials using plant species from arable pasture systems were tested in the vineyard context. The species chosen were intended to either suppress weed germination or growth by providing a mulch on the soil surface. They were also expected to improve soil quality via active root systems and their associated microbiology, while the legumes would supply biologically fixed nitrogen. The reason why this work had not been undertaken before in Australia was the expected yield reduction that would be associated with competition for water and nutrients. It was suspected though that the benefits of improving soil quality by providing active plant growth over the winter and spring period, would then generate improved vine root function, accessing previously unavailable soil moisture. It was essential however that the plants chosen to be sown under-vine either died off or reduced their growth in spring to minimise competition with the vine.

Many pasture species have been bred in Australia with adaption to our Mediterranean environment. The annual legumes and grasses germinate with rains in autumn, grow vigorously into spring then set large quantities of seed before senescing. Perennial native grasses have adapted over thousands of years of evolution, while the exotic species have been bred for summer dormancy to ensure their long-term survival.

In replicated trials, a range of eight annual and perennial native and exotic species were mechanically sown under-vine in commercial vineyards throughout South Australia in 2014. They were compared to herbicide and straw mulch controls. They were closely monitored over three seasons for their growth patterns and impact on the weed populations, vine productivity, grape quality, soil health and ultimately financial returns.

Overall, the results have been very encouraging, to the extent that current practices of maintaining a bare under-vine zone can now be questioned with some authority, as an alternative management strategy can now be tested on a larger scale. At all sites, the growth of annual pasture legumes and grasses as a mixture, or legumes alone, did not reduce productivity, and at 3 out of 4 sites, it was improved. While they did not prevent the growth of weeds, their growth was suppressed significantly. Soil carbon, an important indicator of soil quality, improved significantly, particularly where legumes and grasses were sown as a

mixture. This was achieved at approximately the cost of one year's herbicide application, which should be a one-off cost for purchase and sowing of the pasture seed. With such a low establishment cost and reduced maintenance requirements, plus improved yields, the gross margins increased by up to $1,700/ha, which was achieved at the Barossa site. An initial tasting by Barossa winemakers of wine made from fruit grown and influenced by each of the treatments suggested there is no detrimental effect on quality.

The benefits were not universal across all sites however. The warm, dry Riverland environment provided a considerable challenge. While there was no yield reduction from the legume and annual grasses, they were unable to suppress the growth of some very aggressive summer weeds. Weed control was achieved by an exotic perennial grass species, but at the expense of grape yield.

It is intended to continue this research for another two years. This will enable the delivery of results to grapegrowers with greater certainty and assuredness that the results are real and growers can adopt the practices without penalty. In the meantime, greater awareness of the project through extension efforts and a blog site will occur, and several wine tastings from the 2017 vintage will seek to confirm the benefits or otherwise of under-vine cover crops to the end product.

The financial support of the wine industry and the Australian Government, provided through Wine Australia, is greatly appreciated and acknowledged by the research team. Critical to undertaking this work is the support of many vineyard operators located throughout the South Australian regions. Their staff have been fantastic in accommodating the requirements of this research, which can sometimes impact on their operations. They have also provided in-kind support with mechanical harvesting of the trial, which has reduced the labour costs considerably while providing very accurate yield data, enabled by their skilled operators. Further support from the Australian Wine Research Institute in wine analysis and extension through the roadshow program is greatly appreciated.

BACKGROUND

The under-vine region of the vineyard floor contains the greatest concentration of vine roots, so management of this zone directly impacts vine yield, quality and profitability. However, despite the importance of this zone, it has previously received little research effort committed to improving vineyard profitability. It is estimated that between $7 - 12 million are spent annually in the purchase and application of herbicides for under-vine weed control in Australian vineyards. Up to seven herbicide applications per year are used to maintain this weed free status, but the costs of doing so are likely to extend well beyond the purchase and application costs of the herbicide. The conundrum is that the zone of soil with the greatest level of root activity and potential influence on yield and quality is not being treated in line with best soil management practice because the wrong plants are growing there and needed to be removed.

Murray and Burk (2010) found in the red brown earths of the Barossa Valley, that the sub-soils were inherently poor, with little aeration and high soil strength limiting root penetration and water use efficiency. The authors concluded that gypsum alone would not improve the subsoils and that mulching or the growth of cover crops under the vine row was necessary to ameliorate these soils.

Following that work, Brian Hughes, (Principal Consultant in Soil and Land Management with the Department of Primary Industries and Regions, South Australia), undertook a soil

assessment of Adelaide Hills vineyards in a National Landcare-funded survey. The survey was in response to grower concerns regarding the continual use of herbicides and their potential damage to soil biota, structural decline and increased lichen and moss on the soil surface. Soil organic carbon levels, which correlated strongly with microbial biomass levels, had deteriorated significantly in the bare under-vine area, as shown in Figure 1. Vineyards using biodynamic principles including no herbicides had maintained soil carbon levels similar to those in the grassed mid-row. Suggested solutions to the reduced soil carbon levels and the associated issues of soil degradation were the addition of compost or the use of pastures grown under-vine (Hughes, 2015).

In concert with the recommendation of Hughes (2015), this project aimed to develop novel under-vine management systems that would ultimately minimise or negate the need for herbicides, cultivation, mowing or imported mulching of the under-vine area while being self-perpetuating. Only commercially available plant species and cultivars were chosen to ensure any outcomes were readily adoptable by growers. Preferably, the annual plants would display a prostrate form, early senescence and provide nitrogen fixation in the legumes. These desirable species would be self-regenerating annuals or summer dormant perennials whose winter activity would smother the growth of other weeds, provide root matter to improve soil structure, then senesce either before extracting valuable moisture or later where excess vigour is an issue. This environmentally benign approach to under-vine weed management was anticipated to provide considerable cost savings to the industry while maintaining or improving vine yield and fruit quality.

In addressing vineyard profitability, this project recognises the importance of natural capital and in particular the soil and its inherent biology, and how improving soil quality may improve profitability. This is being achieved without the costly importation of mulches or composts, but instead has utilised the capacity of desired plant species to compete with weeds, thereby reducing the herbicide inputs required by conventional vineyard floor management practices.

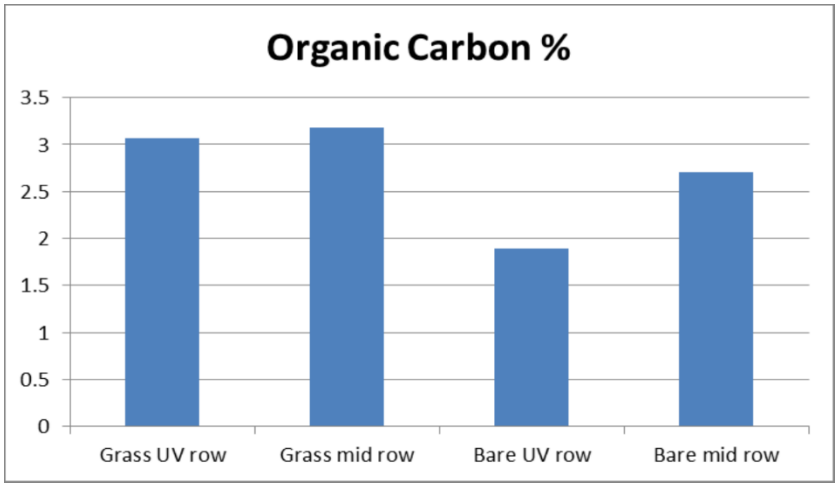


Figure 1: Mean organic carbon percentage of bare (conventionally managed) under-vine areas compared with the mid row and grassed under-vine (from Hughes 2015).

Much of the natural capital of soil is provided by the soil biological community, which is responsible for processes such as biological nitrogen production, soil structural amelioration, pathogen suppression, degrading toxic substances, and the provision of readily available plant nutrients from the soil nutrient pool. Soil contains a hugely diverse bacterial community with

over a billion individual bacterial cells and estimates of from 10^4–10^5 genomes per gram of soil (Fierer et al., 2007). This diversity is driven, in part, by resource partitioning, with different bacterial taxons competing for various subsets of the soil carbon pool. The diversity of soil C substrates is a major factor controlling bacterial species diversity (Zhou et al., 2002).

The main aim for this vineyard soil biology study was to investigate the effect on the soil and grapevine rhizosphere biology of replacing bare soil under-vine with cover crops. The expectation was that cover crops, with both increased root exudation and decomposition of plant matter, would increase the soil organic carbon and thus improve the soil biology, in turn influencing the soil nutrient cycles. Prior to this research, we have shown, using different analytical methods (traditional culturing studies, molecular studies such as T-RFLP, and the Biolog Ecoplate) that under-vine floor management techniques (mulches, composts, herbicide or cultivated treated controls) produced different grapevine rhizosphere microbial 'signatures' in SA and NSW (Whitelaw-Weckert et al., 2007).

Soil/rhizosphere microbial communities antagonistic to vine pathogens may also be enhanced. The enhanced microbial populations also tend to improve soil structure, thereby enhancing vine root access to moisture and nutrients.

The microbial populations (bacteria and fungi) of soil and grapevine rhizosphere collected in 2014 and 2016 were analysed by Next Generation Sequencing (NGS). The computations for Eden Valley and Waikerie were not completed at the time of writing this report due to the delayed access to data. This will be addressed in future papers for peer reviewed journals.

PROJECT AIMS

- To grow plants under-vine that are beneficial to the grapevine, potentially leading to improved vine yields and or fruit quality
- To reduce or cease the need for herbicide use in the under-vine zone
- To improve soil quality under-vine
- To improve vineyard profitability and ecological sustainability

PERFORMANCE TARGETS

The performance targets pertinent to this report were to:

- determine the effect of under-vine treatments on soil biology
- determine the effect of under-vine treatments on weed suppression, vine nutrition and soil moisture
- produce fact sheets, journal articles and papers and revise the Cover Crop Finder decision support tool
- generate a financial analysis of treatment impacts on vineyard productivity

MATERIALS and METHODS

The project trial sites were located at Nuriootpa, Eden Valley, Langhorne Creek and Waikerie. The site characteristics are shown in Table 1.

Table 1: Location and layout of the four principal research sites for investigation of under-vine cover cropping

Site	Variety	Rootstock	Row width (m)	Vine spacing (m)	Plot length (m)	Vines/ha
Nuriootpa	Shiraz	Own	3.5	2.25	20.25	1271
Waikerie	Merlot	Paulsen	3	2	18	1665
Eden Valley	Shiraz	Own	2.75	1.7	15	1962
Langhorne Creek	Cabernet Sauvignon	Own	2.5	1.7	15.6	2312

The soil properties differed in chemistry, as shown in Table 2, and subsoil texture, with a heavy clay evident at Nuriootpa and deep sand at Waikerie. Surface soil pH was remarkably similar across all sites despite differences in rainfall. Low soil carbon at the Nuriootpa, Waikerie and Langhorne Creek sites was obvious, and supports the findings of Brian Hughes in the Adelaide Hills vineyards. The carbon levels at Waikerie are very low, but given the difficulty in generating carbon in sandy soils (Sanderman et al., 2010) this is not surprising. The Eden Valley soils are of high quality, possibly reflecting the long period of pasture prior to establishing the vineyard. The phosphorus levels at this site are very high, negating the need for any application for many years. Otherwise the soil chemistry across all sites is quite sound, with neutral pH and cations approximately in balance.

Table 2: Antecedent soil analysis of the four research sites for under-vine cover cropping

		Barossa	**Langhorne Creek**	**Waikerie**	**Eden Valley**	**Approx. critical /ideal values**
Depth		0-10 cm	0-10 cm	0-10 cm	0-10cm	
Colour		Brown/grey	Brown	Brown-red	Grey	
Gravel	**%**	0	0	0	0	
Texture		Loam/clay	Loam/clay	Loam	Loam	
Ammonium Nitrogen	**mg/kg**	3	2	2	2	0-5
Nitrate Nitrogen	**mg/kg**	8	3	15	17	10-50
Phosphorus Colwell	**mg/kg**	44	38	17	111	>25-35
Potassium Colwell	**mg/kg**	156	97	79	312	>80-120
Sulfur	**mg/kg**	3.7	12.9	4.0		>6-8
Organic Carbon	**%**	0.75	0.92	0.41	1.98	>1-2
Conductivity	**dS/m**	0.065	0.101	0.064	0.150	<6
pH Level ($CaCl_2$)	**pH**	6.4	6.9	6.2	6.3	5.5-7.5
pH Level (H_2O)	**pH**	7.0	7.6	6.8	7.0	6-8
DTPA Copper	**mg/kg**	9.29	5.22	9.06	2.80	>0.2
DTPA Iron	**mg/kg**	28.01	12.65	16.70	71.32	>2.5
DTPA Manganese	**mg/kg**	4.10	6.50	3.67	4.45	>1-2
DTPA Zinc	**mg/kg**	1.66	2.56	2.88	4.69	>0.5 - 1.0
Exc. Aluminium	**meq/100g**	0.040	0.051	0.096	0.013	0% of CEC
Exc. Calcium	**meq/100g**	4.93 (70%)	6.83 (70%)	2.64 (64%)	7.21 (73%)	75% of CEC
Exc. Magnesium	**meq/100g**	1.58 (23%)	2.04 (22%)	1.17 (28%)	1.75 (18%)	20% of CEC
Exc. Potassium	**meq/100g**	0.33 (2%)	0.23 (2%)	0.20 (5%)	0.48 (5%)	5% of CEC
Exc. Sodium	**meq/100g**	0.19 (2%)	0.59 (6%)	0.11 (3%)	0.50 (5%)	<6% of CEC
Boron Hot $CaCl_2$	**mg/kg**	0.56	0.75	0.39	0.68	1-15

Ten treatments were replicated four times in a randomised complete block design, with each plot consisting of three panels, each with three vines. Following leaf fall in 2014, herbicide (glyphosate 540 g.a.i./L @ 2.0 L/ha and oxyfluorfen, 240 g.a.i./L @ 75 mL/ha) was applied to

provide weed control. Plots were sown using a Taege® vineyard disc seeder, with a single row sown each side of the vines at a depth of 10 mm within 20 cm of the vine trunk, with chains behind the disc to cover the seed. No fertiliser was applied, but the legumes were inoculated with the appropriate rhizobium strain. Red legged earth mite, lucerne flea and sitona weevil were controlled as required with chlorpyrifos @ 350 mL/ha. The herbicide controls were maintained as bare earth with herbicide applications (glyphosate) as required. Triticale straw mulch was applied at 55 t/ha to the one metre wide under-vine zone. Importantly, all plant species were allowed to fully express their phenology with no intervention used to manage or terminate growth. Seasonal conditions restricted cover crop growth and seed set in the first year, requiring some treatments to be re-sown in the second year. Cover crop productivity was high in both the second and third years.

Cover crop composition and dry weight was estimated three times per year using the Botanal methodology (Tothill et al., 1978). Vine vegetative production was determined from pruning weights, while vine canopy balance was estimated using the leaf area index generated by the VitiCanopy smartphone App (De Bei et al., 2015). Petioles were sampled at 80% flowering for tissue nutrient analysis and vines were mechanically harvested and weights determined using load cells on a trailer which followed the harvester. Hand harvested fruit was used for winemaking, which followed the red winemaking protocols established by the Australian Wine Research Institute, using 10 L demijohns for the secondary fermentation. Wine sensory evaluation was conducted by a 26-member panel of Barossa Valley winemakers, using a 20 point scoring system. Financial risk profiles and gross margins analysis were developed for all sites, using current costings and yield figures derived from the trial outcomes.

To assess the cover crop impact on soil biology, three soil cores (0-30 cm) were collected from randomly selected positions under the trial grapevines. The three cores were bulked and transported to the laboratory on ice. In the laboratory, grapevine roots were carefully removed from the soil and loosely adhering soil was removed by shaking. The tightly adhering rhizosphere soil was then removed by carefully separating it from the roots with a paintbrush. The rhizosphere soil was placed aseptically into sterile polyethylene screw cap tubes and stored at -80ºC.

DNA was extracted from 0.25g soil samples using a Powersoil-htp Soil DNA isolation kit (MO BIO laboratories, CA) following the manufacturer's instructions. DNA was quantified using QUBIT 2.0 fluorometer (Life Technologies, USA) and subsequently used as template for PCR amplification of the 16S rRNA gene (V4 region) using the universal PCR primer set 515F and 806R, targeting members within both bacterial and fungal domain. The forward primer included the addition of an Ion Torrent PGM sequencing adapter, a GT space and unique Golay barcode to facilitate multiplexed sequencing. The barcoded PCR reaction (20 µL) consisted of: template DNA (1ng), universal primer mix (untagged 515F and 806R at a final concentration of 0.2 µM), tagged 515F primer (0.2 µM), 600ng BSA (Life Technologies) and 2.5x 5Primer Hot Master Mix (5 Primer, Australia). The PCR reactions conditions were 94ºC for 2 min (denaturation), followed by 25 cycles of denaturation at 94ºC for 45 seconds, annealing at 53ºC for 60 seconds, elongation at 72ºC for 90 seconds and a final extension step at 72ºC for 10 minutes. Following PCR amplification, PCR products were checked for size and specificity by electrophoresis on 2.5% w/v agarose gel, purified using Ampure (Beckman Coulter, Australia), quantified and pooled for multiplex sequencing on an Ion Torrent PGM. Quality filtered sequences were subsequently analysed through the Quantitative Insights into Microbial Ecology (QIIME) pipeline (Caporaso et al., 2010). Briefly, the quality parameters used for analysis were: minimum average quality score of 20, minimum sequence length of 130 bp, maximum sequence length of 350bp, no primer mismatch or barcode error allowed. The maximum length of homopolymers was 15 and

maximum number of ambiguous bases was six. De novo OTU picking was performed using UCLUST at 97% sequence identity and subsequently taxonomy was assigned to each OTU based on the Greengenes database (version 13.8). The resulting OTU tables at different levels were used as measures of taxa relative abundance.

Departure from original methodology

For various reasons, not all sites originally proposed either began or continued their existence for the full three years of the project.

The Adelaide Plains site did not eventuate due the death of the owner and a subsequent change in management. The Griffith site was sown in 2014, and included a mid-row cover crop trial funded by the local grower organisation. There was considerable enthusiasm and support for the trial from the host vineyard and the local grower organisation. The site established well and had a committed technician to look after it. Unfortunately, the company decided to turn the vineyard into a water retention dam for the winery. There were only a few weeks available to collect the samples required for the first year's output before it was bulldozed. To partially compensate for the loss of the trial site, a glasshouse trial was established to investigate the allelopathic impacts of several cover crop species on young grapevines.

The Clare site ran for two years until new owners decided that the planted variety (Nebbiolo) was no longer required and it was top worked, preventing the measurement of vine response to the cover crop treatments.

The McLaren Vale site did not respond to the numerous attempts at sowing that were tried. The site is managed organically, so they cannot maintain a clean under-vine zone. As such, the weed seed burden was considerable, and it was very difficult to reduce the weed populations prior to sowing using only cultivation. This outcome is unfortunate as organic growers often have issues with weed control and supporting their management system with an alternative strategy would have been desirable. It has however been a tremendous learning exercise for all concerned.

Coonawarra has had mixed success. Spring rainfall in both 2014 and 2015 was poor, which badly compromised the seed set of the annual species. Regrowth was also restricted at this site by the smothering effect of leaf fall. The perennial species and one annual species still performed well and useful data have been generated. The Adelaide Hills site changed location from Lenswood to Eden Valley. All other aspects of the methodology have proceeded as originally intended.

Enhancements made to the original methodology

Critical to understanding the influence cover crops have on vine growth was the capacity to accurately determine the amount of cover crop biomass produced. Through collaboration with Dr Mark Norton of DPI NSW, the pasture measurement tool Botanal (Mannetje and Haydock, 1963) was used in this project. It was developed by CSIRO to provide a rapid but accurate assessment of botanical composition and dry matter production and is well suited to this application. Three times per year, three 0.25 m^2 quadrat samples each side of the vine row per plot were visually assessed against pre-determined benchmarks, generating 1440 entries per site. These were manually entered into a spreadsheet from which graphs provided an accurate account of green plant biomass from the multiple species present.

Another very useful enhancement was being able to mechanically harvest the plots and capturing the yield data with a weigh bin trailer following the harvester. A frame complete

with load cells was constructed to fit inside an 8x5 trailer which carried either Nally bins lined with bulker bags or a coffin bin. The trailer followed the harvester which stopped and emptied at the end of each plot. With the scales providing ± 0.5 kg accuracy, harvesting using this system provided a cost-effective mechanism of capturing yield data on larger plots, with the operation taking under two hours per site for 40 plots.

The Tea bag index measures decay of plant material by the soil biota using two types of tea bags (green and rooibos). Tea bags are placed in the soil and weight loss is determined after three months. With the decay of easy to decompose green tea one can determine how much of the labile fraction of the material is decomposed and how much is stabilised. Rooibos tea decomposes much more slowly and after three months, it is still in the first phase of decomposition.

Seasonal variation between sites

As shown in Figure 2, mean monthly maximum temperatures vary considerably between the regions, with the Riverland being about 1-4 ^{o}C warmer throughout the year. Eden Valley, with its extra elevation, is cooler than the Barossa (Nuriootpa), while Langhorne Creek, due to the influence of Lake Alexandrina, is cooler during the summer but warmer during winter than the Barossa. Coupled with soil type, rainfall and irrigation management, temperature was an important determining factor on the selection and the performance of the cover crops used in this project.

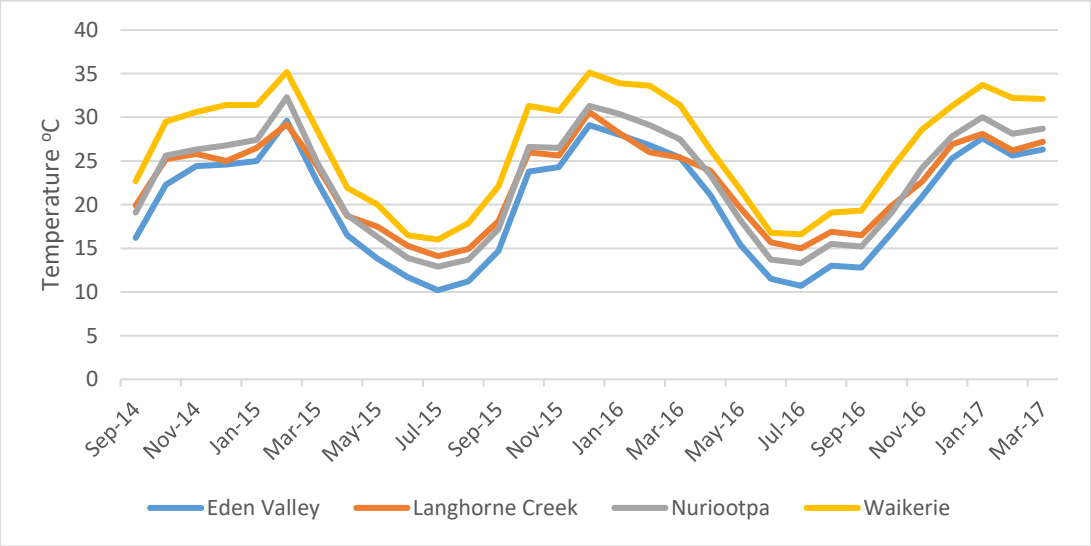


Figure 2: Mean maximum monthly temperatures at the four trial sites, which displays consistent variation between regions.

Trial implementation

All trial sites were designed as a completely randomised block design with 10 treatments and four replicates. The design was checked by a NSW Department of Primary Industries statistician prior to seeding in 2014. Plots were 3-4 panels long, ranging in length from 15 – 20.25 m. All sites were planted to red varieties, with Shiraz at Nuriootpa and Eden Valley, Merlot at Waikerie and Cabernet Sauvignon at Langhorne Creek. All sites were drip irrigated at rates depending on rainfall and desired yield.

Cover crop species were selected based on their growth habit (prostrate or upright), perennial or annually self-regenerating from their own seed bank, seed availability and cost and likely

benefit to soil quality and vine productivity. The species consisted of a core group at all sites (Kasbah cocksfoot, wallaby grass and annual fescue) then medic, sub-clover, strawberry clover and fescue treatments were modified for each site (Table 3). All legumes were treated with the appropriate rhizobium inoculum immediately prior to sowing. Triticale mulch was not applied at Waikerie as it is an impractical treatment due to the cost of transporting straw to the Riverland.

Sites were sown in autumn 2014 using a Taege® seeder, with one row sown within 20 cm of the vine trunk on each side of the vine row. Seed produced by the sown cover crops was expected to fill the gap with plants in the following years.

Table 3: Plant species and cultivars used as under-vine cover crops according to site Nuriootpa (N), Waikerie (W), Eden Valley (EV) and Langhorne Creek (LC).

Common name (cultivar)	**Scientific name**	**Seeding rate (kg/ha)**	**Plant type**	**Site used**
Cocksfoot (cv. Kasbah)	*Dactylis glomerata*	8	Summer dormant perennial grass	N, W, EV, LC
Rats tail fescue (cv. Zorro)	*Vulpia myuros*	10	Annual self-regenerating grass	N, W, EV, LC
Wallaby grass	*Rytidosperma geniculata*	10	Native perennial grass	N, W, EV, LC
Strand medic (cv. Angel); Barrel medic (cv. Sultan)	*Medicago littoralis* *Medicago truncatula*	20 20	Annual self-regenerating legumes	N, W, EV, LC
Spineless burr medic (cv. Scimitar); Annual ryegrass (cv. Safeguard)	*Medicago polymorpha* *Lolium rigidum*	20 30	Annual self-regenerating pasture legume and grass	N, W, EV*, LC *Note: Scimitar replaced with Mintaro clover at this site
Burr medic (cv. Cavalier); Button medic (cv. Bindaroo)	*Medicago polymorpha var brevispina* *Medicago orbicularis*	20 20	Annual self-regenerating legumes	N, W, EV, LC
Strawberry clover Sheep fescue	*Trifolium fragiferum* *Festuca ovina*	20 3	Perennial legume and grass	N, EV, LC
Gland clover (cv. Prima) Sub clover (cv. Mintaro)	*Trifolium glanduliferum* *Trifolium subterraneum ssp. brachycalycinum*	7 20	Annual self-regenerating pasture legumes	N was the only site with Prima sown. Mintaro was sown at EV
Creeping saltbush	Atriplex semibaccata	1 seedling /metre	Prostrate saltbush	Waikerie only
Regenerated weeds	*Medicago spp., Lolium rigidum, Trifolium spp.*			Cavalier and Bindaroo failed at Nuriootpa-reverted to regenerated weeds
Straw mulch (Triticale)	× *Triticosecale*	50 t/ha		
Herbicide control	*Glyphosate 540 g/L*	3 L/ha		Added oxyflurofen (75ml/ha) when required

RESULTS and DISCUSSION

The results and discussion section individually covers the four experimental sites, namely Nuriootpa, Waikerie, Eden Valley and Langhorne Creek, respectively.

Nuriootpa

Seasonal conditions

As shown in Figure 3, there were marked differences in rainfall over the three year trial period. Spring rainfall in 2014 and 2015 was low, and this had implications for the annual cover crops which needed to set enough seed to enable regeneration the following year. This was not the case, necessitating the re-sowing of some treatments in 2015, which also had a dry spring. Seed set was however adequate in the second year to enable regeneration in 2016. By contrast, record spring rainfall and mild temperatures in 2016 provided excellent conditions for the cover crops and the vines.

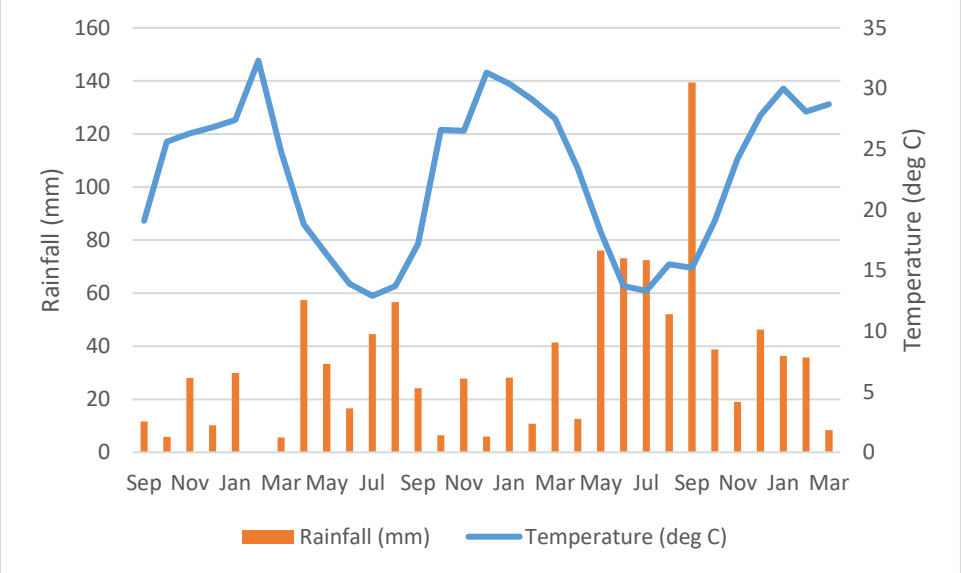


Figure 3: Monthly rainfall and average monthly maximum temperature over three growing seasons from September 2014 until March 2017, Nuriootpa, South Australia.

Cover crop treatments

The Nuriootpa site has a duplex soil type similar to much of the farming land in the South Australia. A selection of species expected to perform their required function was chosen based on prior knowledge. Unfortunately, the Cavalier and Bindaroo medics did not perform well at this site and were removed. In 2016 the treatment was sown to tillage radish which also performed poorly and was removed. It now expresses the weed seed bank at the site and is sprayed out in spring. Refer to Table 3 for species used at this site. Plate 1 shows photographs of cover crops at the Nuriootpa site.

Botanical composition of cover crops

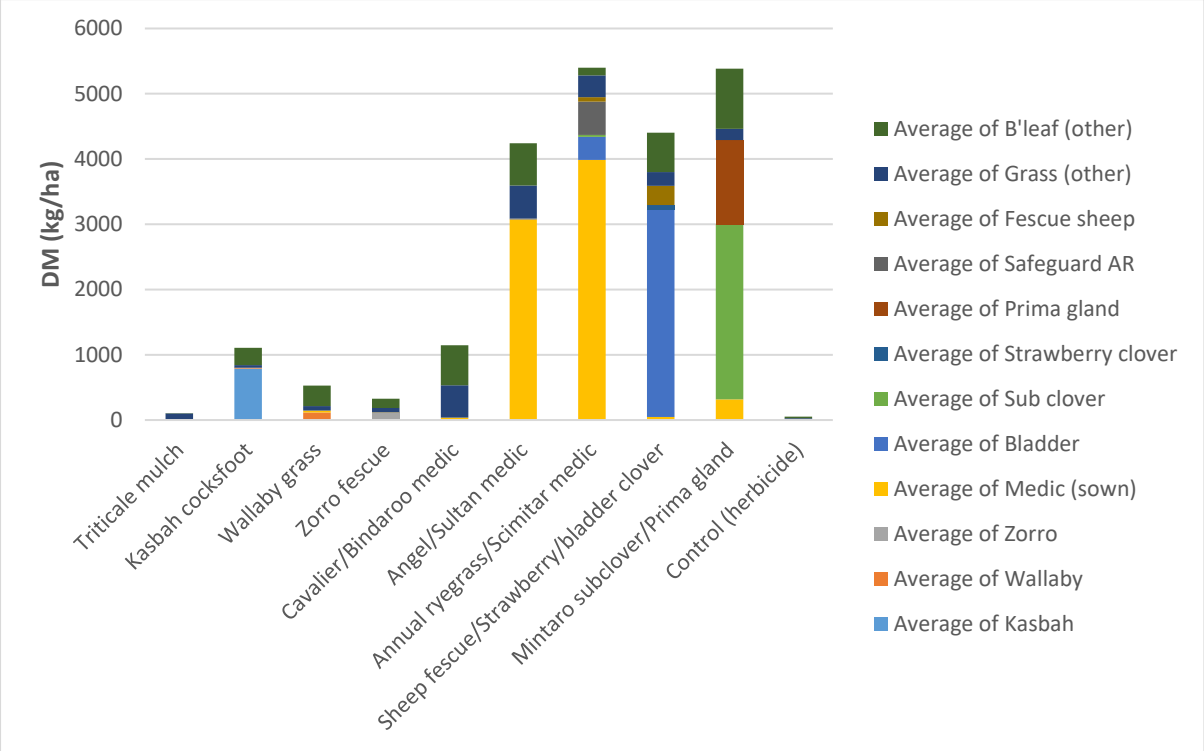
To accurately determine a causal relationship between the cover crop treatment and the soil and vine response, the pasture assessment tool Botanal was used to provide information on

the dry matter production of crop and weed species. The output for spring in 2015 and 2016 is shown in Figure 4.

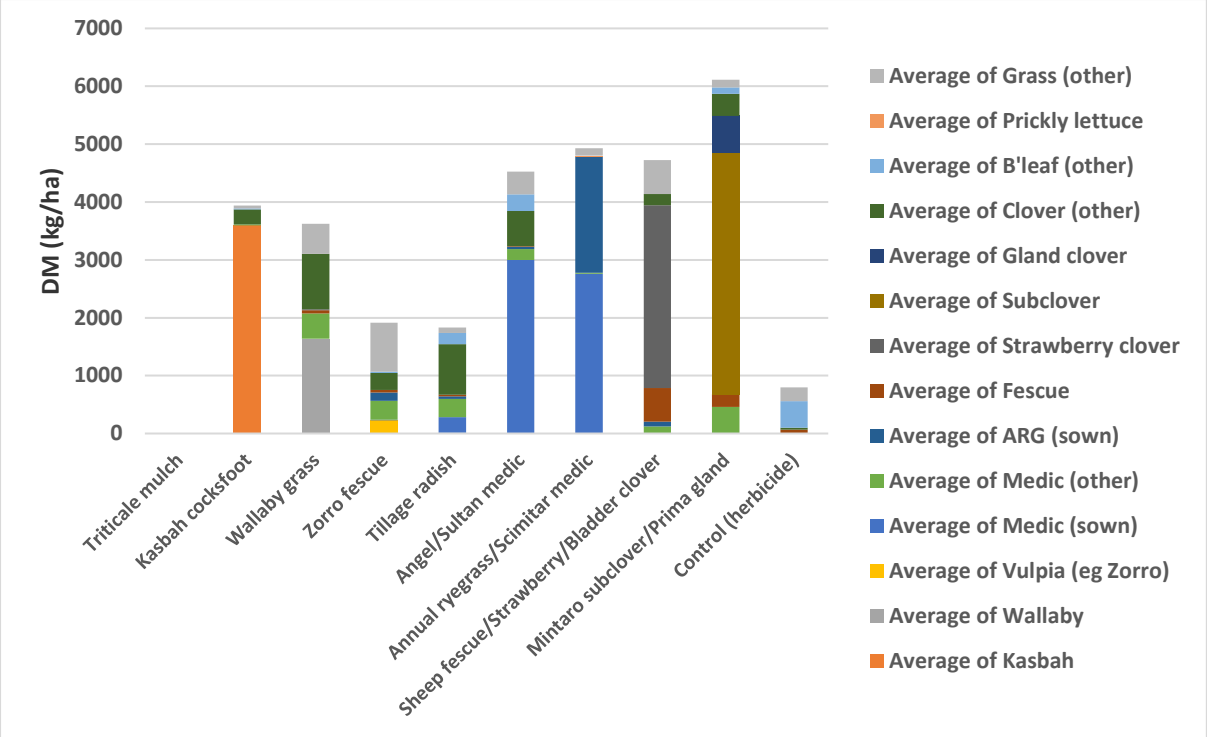
Dry conditions in 2014 and 2015 hampered the growth of all but the medic and clover cover crops, as expressed in the poor dry matter production of the perennial species. There also appears to be, though only anecdotal, a period required for soil, which has supported no plant growth for a long time, to adjust to the new scenario. It is expected that this is due to soil borne pathogens (Hendriks et al., 2013) being able to dominate in a microbially impoverished soil environment, and in this case they may have particularly targeted the grass species and inhibited their growth. Attempts to grow cereals under-vine failed dismally at this site, but worked very well in healthier soil at Eden Valley.

The 2016 cover crop growth was excellent in most species. The Cavalier/Bindaroo medic mix was replaced with tillage radish in 2016, with the intention of using its bio-drilling ability to open up the soil structure. Even this species struggled in these conditions, with the root tending to protrude from the soil surface rather than penetrating the sub-soil as intended. It was also removed in spring 2016.

Important to note in the botanical composition is the dominance of sown species compared to weeds across the treatments. One aim of the project was to reduce the need for herbicides to control weed growth. This appears to have been achieved by most treatments over this trial period, though some weed control may still be required. This would however depend on the weed species involved and grower tolerance to weed escapes.



(a)



(b)

Figure 4: Under-vine cover crop botanical composition and dry matter production, Nuriootpa, spring 2015 (a) and 2016 (b)



(a)



(b)



(c)



(d)

Plate 1: Photos taken on 2 November 2016 at Nuriootpa showing the range of cover crop treatments (a) herbicide control (b) Mintaro sub-clover (c) Kasbah cocksfoot and (d) ryegrass and medic.

Vine yield

In 2015 there were no significant differences in yield, as cover crops had not developed sufficiently to influence the vines. This changed in 2016 and 2017 to generate some fascinating results from two very different seasons.

As shown in Figure 5, the dry spring conditions of 2015 favoured the mulch treatment, while the annual medics and medic/ryegrass mix performed as well as the herbicide control. The imported triticale mulch, which suppressed weed growth and reduced evaporative losses yielded higher than the perennial grasses (fescue, cocksfoot and wallaby grass) and the sub-clover/gland clover mix. The reasons for this need to be interrogated further. Under dryland conditions both the wallaby grass and cocksfoot are genetically primed to go dormant when access to soil moisture ceases in spring. However, under irrigation we found that the dormancy trigger was over-ridden and both of these species maintained green growth, removing soil moisture that the vines would have otherwise used. As such they will generally be deemed to be unsuitable for most vineyards where water is a limiting factor on productivity. The yield reduction may however be seen as an attribute at particularly wet or vigorous sites that require considerable canopy manipulation to achieve vine balance. Once established, the perennial grasses also provided excellent suppression of weeds, and it is possible they may be responsible for improved wine quality. The potential benefits from these species could be exploited, by spray topping or mowing in spring to suppress growth and reduce competition, a strategy which should be investigated.

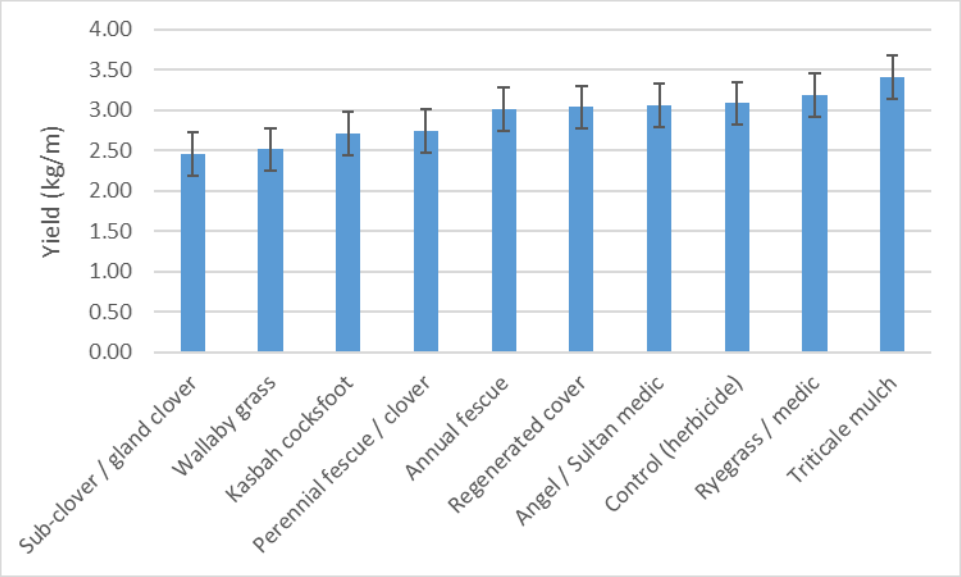


Figure 5: Harvest yields for the 2016 vintage, Nuriootpa.

The Mintaro sub-clover/Prima gland clover blend also performed poorly which was unexpected. A literature search suggests however it is possibly a result of allelopathic interactions between the gland clover and the vine. Wang et al. (2005) found coumarins on the leaf surface and in the leaf of *Trifolium glanduliferum* (cv. Prima) were the primary deterrent mechanism for red legged earth mite which are a significant pest of pastures. It was this attribute that encouraged its inclusion in the species mix, as reducing the need for insecticides was also an important selection criterion. However, Alexieva et al. (1995) noted the plant growth regulating effect of coumarins on stem and root growth of wheat and cucumber, while Razavi (2011) also recognised their fungitoxic nature, which may also impact on arbuscular mycorrhizal fungi (AMF) populations. It is therefore possible this species of clover, which was expected to be desirable as a vineyard cover crop, has reduced grape yields through an allelopathic interaction with the vine in 2016. The Prima clover did not grow in 2016, and the relative yields of that treatment increased considerably.

In 2017, the ryegrass/medic, pure medic and mulch treatments all had higher yields than the annual fescue and the herbicide control (Figure 6). The trend towards higher yields, even from the perennial grasses and clover was encouraging. For two years the annual medics performed very well, and when combined with ryegrass there was no apparent yield penalty. This is a tremendous outcome for this site and potentially for Barossa growers. There was a 28% yield increase from the herbicide control to the ryegrass/medic treatment, which at $2,000/t, equates to a $5,000/ha increase in returns. This is on an initial investment of less than $200/ha for the seed and sowing.

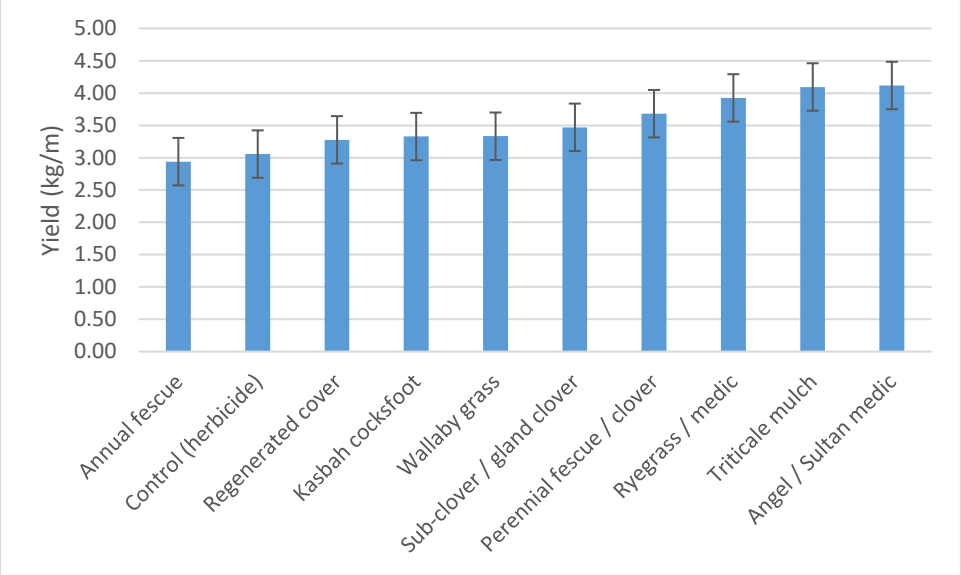
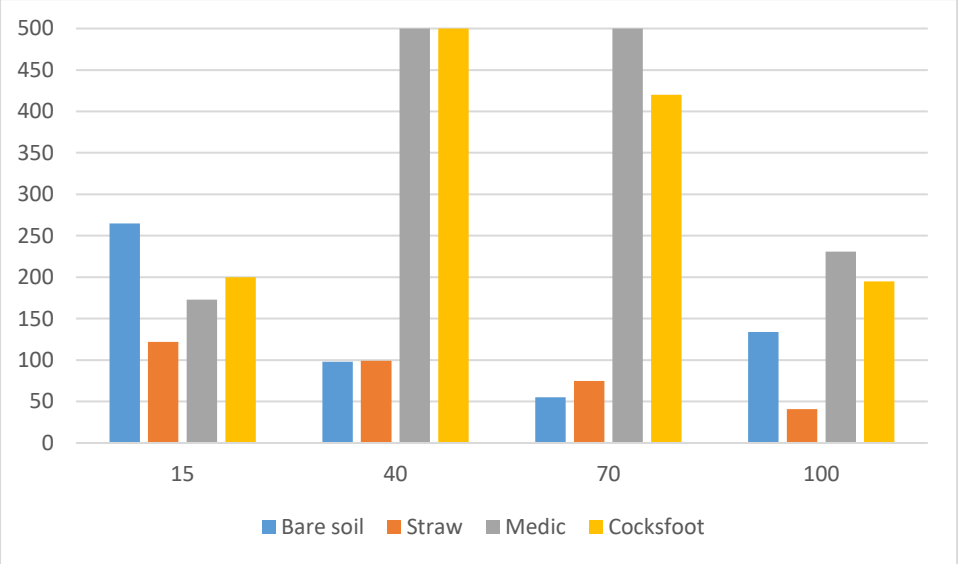
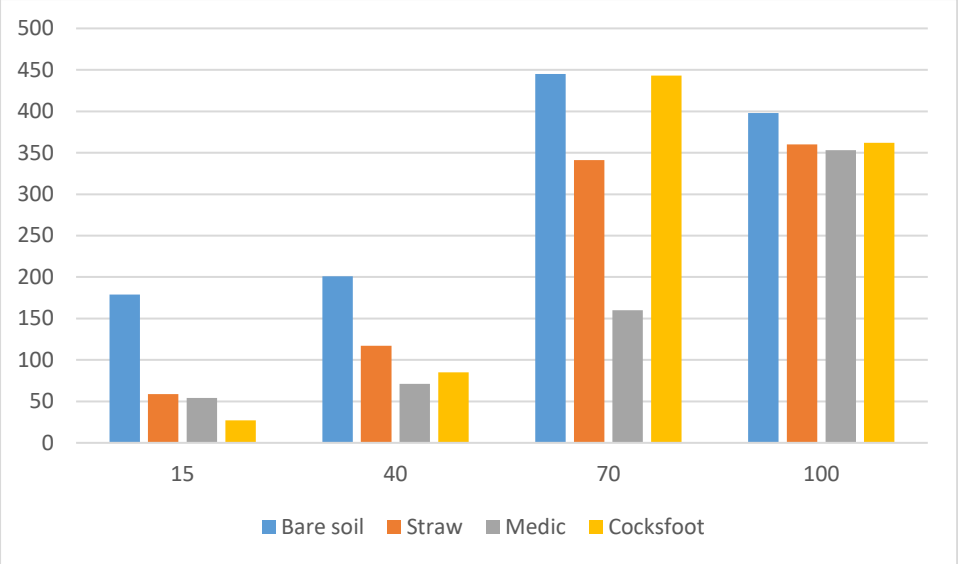


Figure 6: Yields obtained from the Nuriootpa trial site in 2017

The mechanisms behind this yield gain are however unclear. Undoubtedly it involves soil moisture availability, but how that is being improved by some cover crops is still to be determined. The soil moisture tension figures, Figure 7 (a) and (b), show different extraction regimes between different treatments over four depths.



(a)



(b)

Figure 7: Soil moisture tension determined using gypsum blocks for flowering (a) and harvest (b) times in the 2016/17 season.

The soil moisture tension figures shown above provide an insight into how the cover crops are influencing water availability to the vines. At flowering in early December 2016 (Figure 7) at 40 and 70 cm of Figure 7(a) the medic and cocksfoot had utilised all available water in the profile (the larger numbers represent greater difficulty for the plant roots to access soil moisture). This is to be expected with the medic and ryegrass, which have exploited the moisture to maximise seed production prior to senescing. The cocksfoot, which is genetically programmed to become dormant over dry summers, has instead responded to the high spring rainfall and remained green and transpiring. Conventional thinking would suggest that the stored moisture has been wasted as the under-vine cover crops have used water that should have been available to the vine. However, the yield figures do not support that finding. The ryegrass/medic treatment where the gypsum blocks were located was at the high end of the yield spectrum. The cocksfoot, which did not go completely dormant, continued to utilise soil moisture until harvest (Figure 7(b)), and the vine yield suffered as a result, though was no worse than the control. By comparison, the high yielding medic treatment, was conservative in its water use, as shown at the 40 and 70 cm depths when compared to other treatments. How were the vines on this treatment able to produce high yields with less water in the soil profile? The reason is unclear but we consider it is due to enhanced soil biology generated by the cover crop improving conditions for root growth. Enhanced mycorrhizae populations may be exploring a larger soil volume than is possible with low populations, as the vine roots are poorly branched and have few root hairs. The soil type (duplex, with a dense heavy clay sodic sub-soil) is very hostile to root growth and access to water (Murray and Burk, 2010). The very fine mycorrhizae hyphae, which may extend to 30 cm from the vine root, have a greater capacity for penetration into these soils. This is a theoretical assumption at present. Had there been differences in soil strength at depth, then it may have been assumed that improved soil structure enabled better vine root access, but this was not the case.

Penetration resistance

To gain an impression of the impact the cover crops were having on soil structure, resistance to penetration was measured using a penetrometer. The results from the 2017 measurements are shown below, with significant differences being apparent at the 10 and 20 cm depths. This is not surprising given that many annual species including ryegrass and silvergrass have

at least 50% of their roots in the top 10 cm of soil (Ozanne et al., 1965). At both depths the control and the regenerated cover (which is also removed with herbicide) has the highest resistance and the mulch along with grasses (silvergrass and fescue) the lowest. The fibrous root systems of grasses are particularly effective at improving soil structure (Cockroft, 2012), and this may be the mechanism which has reduced penetration resistance in the upper 20 cm of soil. Approximately 2000 kPa is recognised as the limit of resistance to penetration for most plant roots. As shown in Figure 8, this was reached for most treatments at about 40-50 cm deep. Access to soil moisture at the Nuriootpa site is therefore largely restricted to the top half a metre or so of soil.

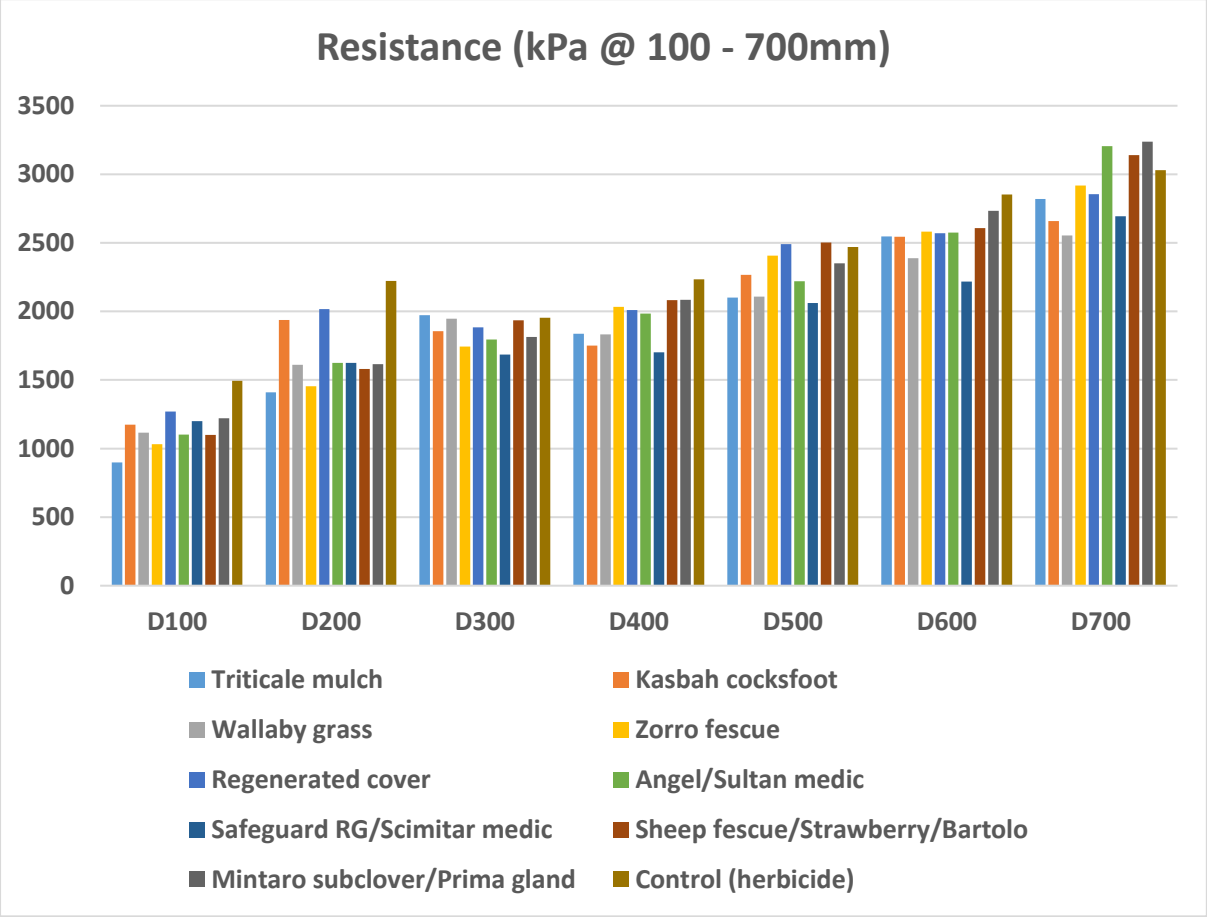


Figure 8: Resistance to penetration measured with a penetrometer, Nuriootpa, 2017.

Petiole nutrition

Nitrogen is the main nutrient required for vine growth, but it also plays an important part in the grape fermentation process and potentially wine quality. Holzapfel and Treeby (2016) noted the need for yeast available nitrogen (YAN) in the primary fermentation, with residual N also assisting in malolactic fermentation and maintaining wine stability. Petiole nitrogen concentration measured at flowering is suggested by Holzapfel and Treeby (2016) as providing a useful guide to the YAN in fruit at harvest. They also state that the nitrogen status of the vines at flowering is directly correlated to the post-harvest nitrogen supply, which is stored in vine tissue during dormancy and is the main source of N until flowering. At the Nuriootpa site there was no correlation between petiole N and YAN levels in 2016/17. These recommendations would therefore appear to not be applicable when dealing with the under-vine cover crops at this site, where N provided by legumes may be supplying N over the

summer period and thereby raising YAN levels. The above average rainfall season provided very different results to 2015/16, where there was a direct correlation (r^2=0.99, Figure 9) between YAN and petiole N. Aside from the seasonal differences and the possible impact on mineralisation rates it is difficult to determine with certainty why the two years were so dissimilar.

At the Nuriootpa site in 2016/17 petiole N was higher on the treatments with no cover crop, probably coming from N supplied in post-harvest fertigation being available to the vines where there was no cover crop growth. The cover crops, including the legumes, will have used available soil nitrogen over their growing season (winter/spring) for both vegetative and reproductive growth, leading to lower petiole N concentrations. However, as the mineralisation of the organic matter occurs over the growing and maturing period for the vines, N is made available to the maturing fruit, thereby raising YAN levels. For red wine the minimum/maximum YAN is 100 and 470 mg N/L respectively, so the results gained fit neatly within those boundaries.

Holzapfel and Treeby (2016) also note the detrimental effects on wine of excess nitrogen, including the production of ethyl acetates, volatile acidity and acetic acid. Given the potential for the cover crops to produce in excess of 100 kg/ha of nitrogen in the vine row, it will be interesting to monitor the YAN levels and wine quality as the trial progresses further. Potentially however, the cover crops will have their own self-limiting mechanism whereby grasses successionally populate the legume cover crops and utilise the accumulated N before it becomes a problem. It will be important to monitor YAN levels over the next three years to see if they change with time and cover crop composition.

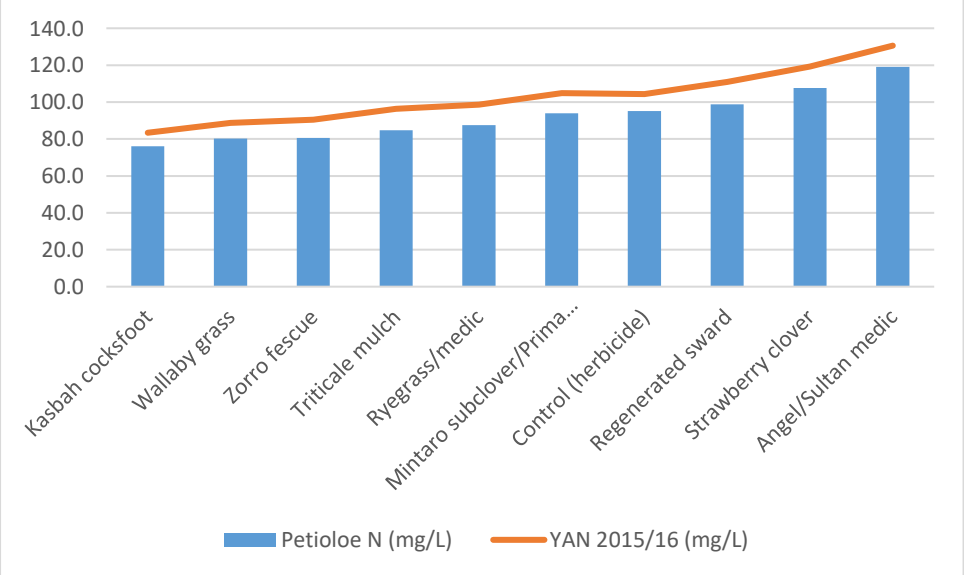


Figure 9: There was an excellent correlation (r^2=0.99) between petiole nitrogen and yeast available nitrogen in the drier 2015/16 season.

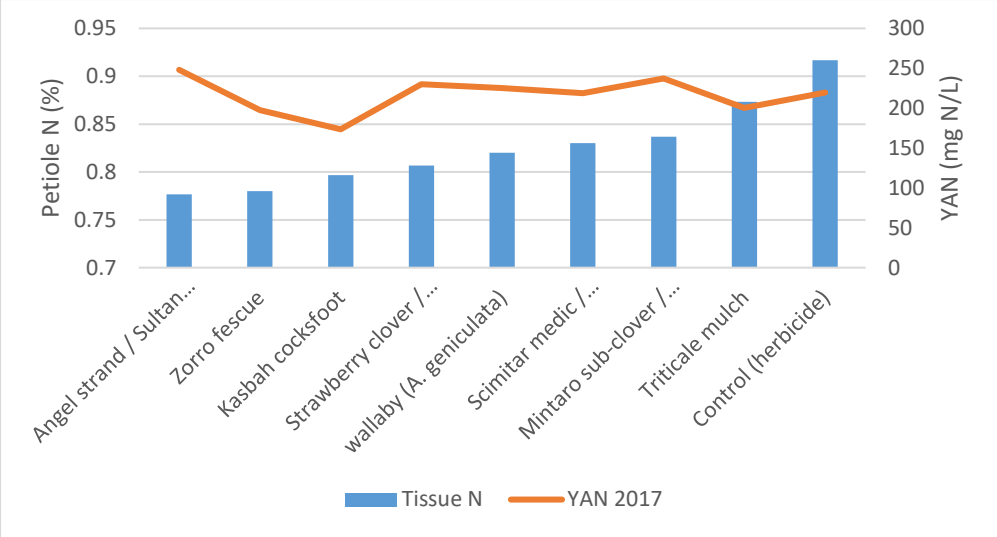


Figure 10: The correlation between nitrogen content of petioles in 2016 and YAN for the wetter 2016/17 season.

Fruit quality and vine responses to cover crops

As shown in Table 4, for the drier 2015/16 season, treatments producing larger canopies and higher LAIe, also produced larger bunches and higher yields. However, the wetter 2016/17 season (Table 5) showed no correlation with canopy size on yield, although YAN did increase with LAIe. With regard to fruit quality, there were no significant differences in 2015/16, and some small but significant differences in titratable acidity in 2016/17. In 2015/16 the Mintaro/Prima clover combination produced the lowest cane numbers and the highest yield to pruning weight ratio. Cane numbers did not translate into yield with cocksfoot having the highest cane number but the lowest yield and the triticale mulch was the reverse. In 2016/17 when soil chemistry was analysed, there were few correlations evident, the exceptions being P and berry weight (r^2=0.67) and soil carbon with bunch numbers per vine (r^2=0.66). Yield to pruning weight (Y:P) ratios were low in 2015/16, with six of the 10 treatments below the recommended minimum of 5. In 2016/17, the canopies relative to fruit yields were smaller on the legume treatments, but there were no differences in Brix suggesting there were adequate canopies to ripen the fruit.

Table 4: Vine and fruit properties for 2015/16

Treatment	LAIe	Crown porosity	Bunches (#/m)	Bunch wt (g)	50 Berry wt (g)	Yield (kg/m)	Brix	TA	pH	Petiole N (mg/L)	YAN (mg/L)	Canes (#/m)	Canes (kg/m)	Y:P
Triticale mulch	1.95d	0.24	26.22d	137.8	51.4	3.41c	22.53	6.70	3.35	84.8	96.3	17.4a	0.68	5.00
Kasbah cocksfoot	1.52cd	0.32	22.33ab	118.2	46.1	2.72a	23.08	6.55	3.37	76.1	83.4	24.02c	0.62	4.35
Wallaby grass	1.49cd	0.27	23.12bc	131.2	48.2	2.52a	23.62	7.09	3.34	80.3	88.8	21.64bc	0.71	3.53
Zorro fescue	1.33ab	0.31	22.6ab	130.1	46.6	3.01abc	23.33	6.63	3.36	80.7	90.4	19.25ab	0.69	4.36
Regenerated cover	1.63bcd	0.27	22.24bcd	133.4	52.2	3.04abc	23.18	7.33	3.34	98.7	110.9	19.92ab	0.82	3.72
Angel/Sultan medic	1.45bcd	0.28	26.97abc	129.1	51.0	3.06bc	23.38	6.70	3.36	119.1	130.6	19.72ab	0.60	5.06
Safeguard RG/Scimitar medic	1.46bcd	0.31	22.11abc	141.9	50.7	3.19bc	23.11	6.96	3.39	87.5	98.6	21.4bc	0.63	5.03
Sheep fescue/Strawberry	1.03a	0.36	26.24a	102.7	53.8	2.74ab	23.06	6.98	3.38	107.6	119.2	17.32a	0.54	5.09
Mintaro sub clover/Prima gland	1.24bc	0.32	18.61ab	105.4	47.9	2.46a	22.67	6.35	3.42	94.0	104.8	18.41a	0.59	4.18
Control (herbicide)	1.82cd	0.27	25.09cd	126.6	51.6	3.09bc	23.28	6.68	3.33	95.1	104.3	19.74ab	0.73	4.21
Site Mean Yield	**1.49**	**0.30**	**23.55**	**125.6**	**49.95**	**2.92**	**23.12**	**6.80**	**3.36**	**92.4**	**102.7**	**19.88**	**0.66**	**4.66**
F pr.	**0.011**	**0.06**	**0.008**	**0.24**	**0.099**	**0.038**	**0.47**	**0.09**	**0.19**	**0.11**	**0.10**	**0.031**	**0.40**	**0.12**
Coefficient of variation %	**NA**	**NA**	**11.4**	**17.7**	**9.8**	**19.4**	**3.8**	**NA**	**NA**	**19.3**	**18.6**	**14.3**	**21.5**	**22.0**
Average LSD (P=0.05)	**0.426**	**NS***	**3.77**	**NS**	**NS**	**0.581**	**NS**			**NS**	**NS**	**3.80**	**NS**	**NS**

Table 5: Vine and fruit properties for 2016/17

	LAIe	Crown Porosity	Bunch (#/vine)	Yield (kg/m)	50 Berry wt (g)	Total Acid (g/l)	Brix	YAN	Total soil N (%)	Total soil C (%)	Colwell P (mg/kg)	Canes (#/m)	Canes (kg/m)	Y:P
Triticale mulch	1.84ab	0.24c	83	4.09bc	71.04	4.64a	22.36	207	0.09a	1.00a	57.01	23.8	0.82	4.67ab
Kasbah cocksfoot	1.68a	0.25c	80	3.3ab	62.18	5.48bc	22.80	186	0.10ab	1.01a	47.22	23.3	0.68	4.73ab
Wallaby grass	2.08abc	0.21bc	82	3.33ab	63.10	4.82a	23.57	232	0.10bc	1.09abc	46.18	25.0	0.74	4.23a
Zorro fescue	2.47cd	0.17ab	84	2.93a	62.58	5.38bc	22.07	211	0.10ab	1.06ab	41.05	23.3	0.72	3.61a
Regenerated cover	2.31bcd	0.19ab	81	3.27a	64.75	5.43bc	22.45	218	0.12c	1.14abc	45.08	22.2	0.71	5.32bc
Angel/Sultan medic	2.75d	0.15a	98	4.11c	60.44	4.43a	22.85	246	0.09a	1.03a	38.18	23.0	0.63	6.43cd
Safeguard RG/Scimitar medic	2.34bcd	0.18ab	90	3.92bc	69.18	4.96ab	21.99	225	0.12c	1.19bc	43.81	22.3	0.71	5.88bcd
Sheep fescue/Strawberry	2.45cd	0.17a	92	3.68abc	63.51	5.50bc	22.07	233	0.11bc	1.23c	51.58	24.4	0.71	5.14bc
Mintaro sub-clover/Prima gland	1.88ab	0.23c	92	3.47abc	61.46	5.84bc	22.33	213	0.11c	1.10abc	41.68	22.5	0.59	7.09d
Control (herbicide)	2.07abc	0.21bc	87	3.05a	66.85	5.78bc	22.86	219	0.09ab	1.00a	54.42	22.9	0.62	5.47bc
Site Mean Yield	**2.192**	**0.206**	**87**	**3.52**	**64.51**	**5.23**	**22.54**	**219**	**0.107**	**1.085**	**46.62**	**23.3**	0.69	**5.26**
F pr.	**0.004**	**0.011**	**0.31**	**0.05**	**0.25**	**0.01**	**0.10**	**0.29**	**0.002**	**0.015**	**0.20**	**0.90**	0.34	**0.01**
Coefficient of variation %	**15.5**	**19**	**12.3**	**13.1**	**8.4**	**8.7**	**3.3**	**13.5**	**8.3**	**8.0**	**21.0**	**12.0**	21	**21**
Average LSD (P=0.05)	**0.493**	**0.057**	**NS**	**0.78**	**NS**	**0.670**	**NS**	**NS**	**0.013**	**0.144**	**NS**	**NS**	NS	**1.48**

Wine quality

Seven of the ten treatments were used to provide fruit for assessment of their impact on wine quality. Of the suite of wine chemistry analysed by AWRI, only anthocyanins displayed differences, as shown in Figure 11.

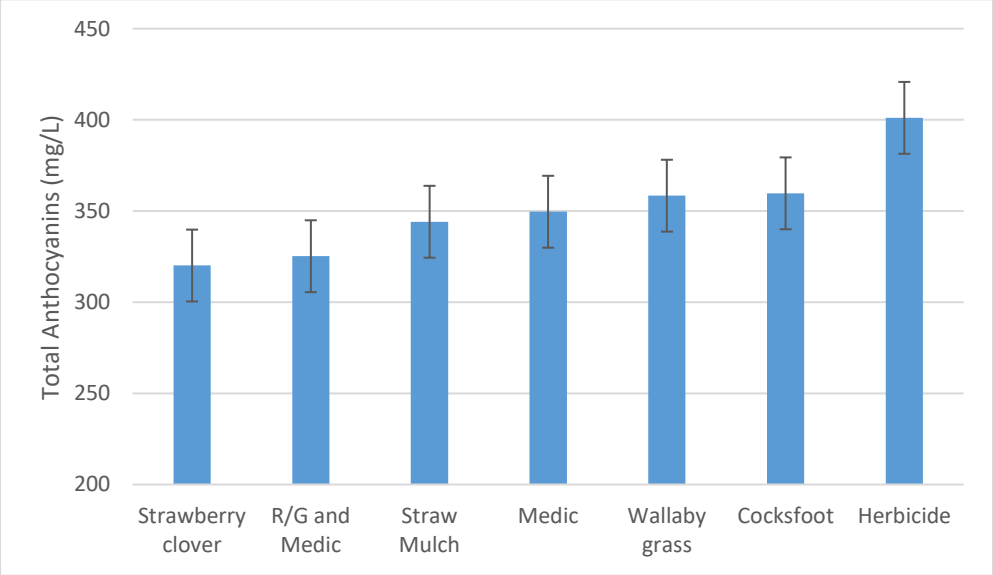


Figure 11: Wine anthocyanin content, Nuriootpa, 2016.

The anthocyanin concentrations were highly correlated (r^2=0.8) with YAN and phenolics (r^2=0.93), but common to small lot winemaking they were not at a high level according to the standards of AWRI.

The wine was also presented at a tasting organised by the Barossa Vine Improvement group at Yalumba in November 2016. Following a presentation providing background to the project, 26 tasters gave a score based on the 20-point scoring system. The results are shown in Figure 12. The wine in general was well received and showed overall a one point difference in ranking from the lowest (herbicide control) to the highest (cocksfoot). While the results are statistically significant, they do only represent one year's data so they are presented with that proviso. However, the results do suggest that from a winemaker / viticulturist perspective, there appears to be no adverse impact on quality from the cover crops, and potentially improvement compared to conventional practice.

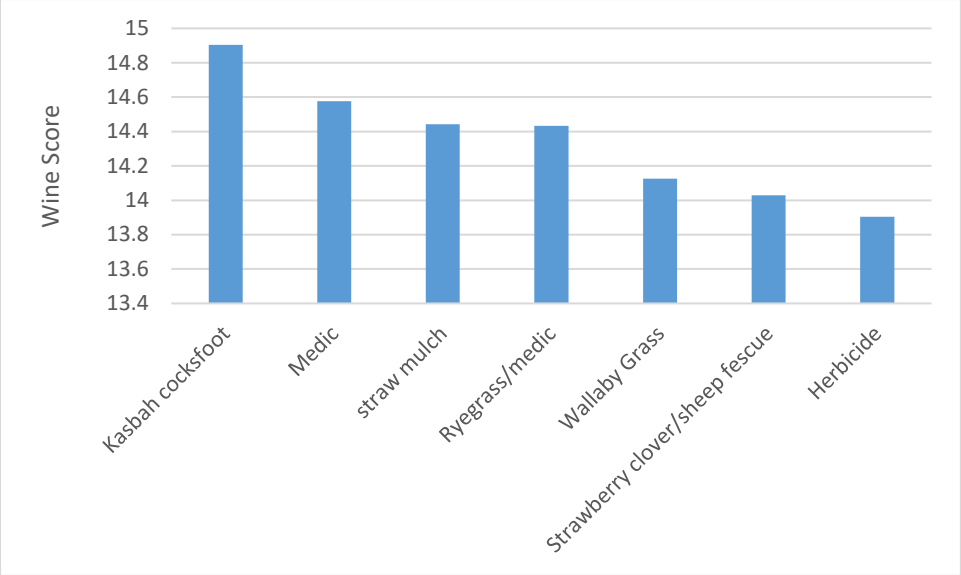


Figure 12: Wine scores relating to under-vine cover crop treatments from a Barossa Vine Improvement tasting event for 2016 Shiraz trial wines.

Soil properties

An important outcome of this project was the capacity for cover crops to improve soil quality, and one of the critical measures is total carbon. As shown in Figure 13, there was significant improvement as the legume content of the cover crops increased. While the strawberry clover/fescue treatment is not practical due to its yield suppression, it did show what could be achieved by a perennial legume and grass combination. The clovers and medics mixed with ryegrass were also strong performers, with a 19% increase in carbon occuring with the latter treatment. This is a significant and important outcome, suggesting it is possible to raise soil carbon quite quickly in the initial phases of amelioration at least. Soil N and P were strongly correlated as expected. Soil P understandably did not change over the three years.

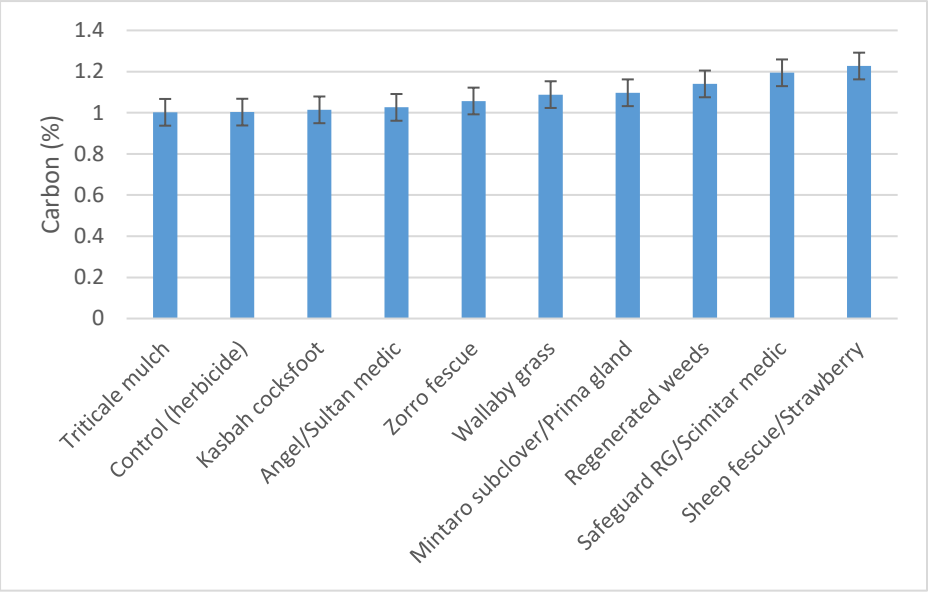


Figure 13: Soil carbon changes following three years of under-vine cover crop, Nuriootpa.

Soil biology

Our results provide evidence that the rhizosphere grapevine fungal community at Nuriootpa was composed primarily of an unidentified class within phylum Zygomycetes (64.7% abundance). The next highest abundance was in phylum Ascomycota (28.4%). There were some significant differences between the grapevine rhizosphere populations of different vineyard treatments. At the Phylum level, the clover treatment (Mintaro sub-clover/Prima gland clover) was associated with higher abundances of Chytridiomycetes, whereas the rhizosphere from Triticale mulch contained higher levels of Glomeromycota and Zygomycota. Abundance of Glomeromycota was also greater in the Zorro fescue treatment (Table 6).

Within the phylum Ascomycota, the main fungal classes were Sordariomycetes (13.6%), an unidentified class (6.03%) and Dothideomycetes (3.11%) (Table 7a). Although there were no significant differences between the under-vine treatments, there was a non-significant trend towards increased levels of Dothidiomycetes with rhizosphere soil from the clover treatment (Mintaro sub-clover/Prima gland clover). Members of Dothidiomycetes identified in the rhizosphere included an unknown member of the family *Botryosphaeriaceae, Capnodium, Cladosporium, Spencermartinsia, Periconia, Phoma, Pyrenochaeta, Leptosphaeria, Lophiostoma, Paraconiothyrium, Paraphaeosphaeria, Phaeosphaeria, Stagonospora, Alternaria, Cochliobolus, Embellisia, Preussia* and four identified genera. Although many of these genera are plant pathogens, none were significantly more abundant for the clover treatment individually (see Table 3) although it is likely that a combination of these genera, rather than one individual genus, may have affected the grapevines in the clover treatment (Table 7b).

Table 6: Fungi level 2 (Phylum) in grapevine rhizosphere soil, Nuriootpa, Spring 2016

Treatment	C5 Asco mycota	**C6** Basidio-mycota	C7 Chytridio mycota	C8 Glomero-mycota	C9 Incertae_sedis	C10 Neocalli-mastigomycota	C11 Zygo-mycota	C12 P unidentified	C13 k unidentified; p_ unidentified
1 Triticale mulch	0.194	-0.023	-0.000019 a	**0.04014 a**	-0.0035	**0**	**0.001862 a**	0.0567	0.734
4 Zorro fescue	0.421	0.061	0.000019 a	**0.01620 a**	0.0136	0	0 a	0.0210	0.467
6 Angel/Sultan medic	0.189	0.025	0.000140 a	0.00035 a	0.0014	**0**	0 a	0.0035	0.780
9 Mintaro sub-clover/ Prima gland clover	0.488	-0.019	**0.001540 a**	0.00203 a	0.006	0	0.000159 a	0.0442	0.482
10 Control (herbicide)	0.128	0.075	0 a	0.00345 a	0.0076	0	0.0001038 a	0.0167	0.769
Mean	0.284	0.024	0.000336	0.01243	0.0039	0	0.0004229	0.0284	0.647
	28.4	2.4	**0.034**	**1.24**	0.39	0	**0.04**	2.84	64.7
P value[1]	0.247	0.769	**0.030**	**0.047**	0.562		**0.014**	0.303	0.552
LSD	0.9667	1.1363	0.0004797	0.018695	0.10416		0.0002709	0.16218	2.3873

[1] Bonferroni multiple test with a significance cut off value of 0.05

There was also a non-significant trend towards increased levels of Eurotiomycetes for the clover treatment. Members of the Eurotiomycetes identified in the rhizosphere included two unidentified fungi plus common rhizosphere fungus *Exophilia,* plant pathogen *Cladophialophora,* and the important trunk disease fungus *Phaeomoniella*. Interestingly, prominent members of Eurotiomycetes, *Penicillium* and *Aspergillus*, were not detected. None of the genera were significantly more abundant for the clover treatment individually (see

Table 3) although it is likely that a combination of these genera, rather than one individual genus, may have affected the grapevines in the clover treatment.

Table 7a: Fungi level 3 (Class) Nuriootpa rhizosphere soil 2016

Order		Total abundance % (100 x mean)
C6	Ascomycota; c__Dothideomycetes	3.11
C7	Ascomycota; c__Eurotiomycetes	0.0348
C8	Ascomycota; c__Incertae_sedis	1.95
C10	Ascomycota; c__Leotiomycetes	0.929
C11	Ascomycota; c__Orbiliomycetes	0.000633
C12	Ascomycota; c__Pezizomycetes	0.0452
C14	Ascomycota; c__Sordariomycetes	13.6
C15	Ascomycota; c__Taphrinomycetes	0.031
C16	Ascomycota; c__unidentified	6.03
C17	Basidiomycota; c__Agaricomycetes	0.982
C19	Basidiomycota; c__Cystobasidiomycetes	0.0329
C21	Basidiomycota; c__Microbotryomycetes	0.00397
C22	Basidiomycota; c__Pucciniomycetes	0.00707
C23	Basidiomycota; c__Tremellomycetes	0.805
C25	Basidiomycota; c__unidentified	1.69
C27	Blastocladiomycota; c__unidentified	0.0263
C28	Chytridiomycota; c__Chytridiomycetes	0.275
C29	Chytridiomycota;c__unidentified	0.683
C30	Glomeromycota; c__Glomeromycetes	0.447
C31	Glomeromycota;c__unidentified	0.0125
C33	Neocallimastigomycota; c__Neocallimastigomycetes	0.0315
C34	Zygomycota; c__Incertae_sedis	2.38
C36	Zygomycota; c__unidentified	66.9

Table 7b: Fungi level 3 (Class) in grapevine rhizosphere, spring 2016, Nuriootpa

Treatment	**C6 P Ascomycota; Dothideomycetes**	**C7 Ascomycota; Eurotiomycetes**	**C8 Ascomycota; Incertae_sedis**	**C10 Ascomycota; Leotiomycetes**	**C11 Ascomycota; Orbiliomycetes**	**C12 Ascomycota; Pezizomycetes**	**C14 Ascomycota; Sordariomycetes**
1 Triticale mulch	0.0407	0	0.0273	0	0	**0**	0.170
4 Zorro fescue	0.0340	0.000083	0.0299	0.0199	0.000011	0.00131	0.083
6 Angel /Sultan medic	0.0133	0.000022	0.0056	0.0011	0.000022	0.00033	0.078
9 Mintaro sub-clover/ Prima gland clover	**0.0990**	**0.001773**	0.0141	0	0	0	0.406
10 Control (herbicide)	0.0069	0.000269	0.0246	0.0252	0	0.00091	0.065
Mean	0.0388	0.000413	0.0203	0.0053	0.0000022		0.160
P [1]	0.102	0.083	0.344	0.670	0.661	0.333	0.358
l.s.d.	0.08976	0.0015433	0.08783	0.32845	0.00028	0.007302	1.2957

[1] Bonferroni multiple test with a significance cut off value of 0.05

Although not statistically significant, the levels of Sordariomycetes appear to be raised in the clover treatment, although a larger number of replicates may be needed to show this. Members of class Sordariomycetes identified in the rhizosphere included *Phomopsis*,

Bionectria, Codrdyceps, Pochonia, Trichoderma, Acremonium, Myrothecium, Stachybotrys, Cylindrocarpon, Fusarium, Gibberella, Haematonectria, Nectria, Neonectria, Volutella, Cryptovalsa, Plectosphaerella, Colletotrichum, Humicola, Ramophialophora, Schizothecium, Pestalotiopsis, Truncatella, Microdochium, Monosporascus and nine unidentified fungi. Although many of these genera are plant pathogens, only three, the pathogens *Volutella, Truncatella,* and an unknown genus, were significantly more abundant for the clover treatment individually (see Table 3). It is likely that a combination, rather than individual genera, may have affected the grapevines in the clover treatment**.**

Three genera within the Class Sordariomycetes (plant pathogens *Volutella* and *Truncatella* plus an unidentified member of family Hypocreales) had significantly higher abundances in the clover treatment. One member of Basidiomycota (*Sebacina*) was absent within the clover treatment and had significantly higher abundance in the Zorro fescue and medic treatments. Some species of *Sebacina* have plant growth promoting qualities. One unidentified genus within Blastocladiomycota (C299) had significantly higher abundances in the clover treatment. This phylum is known to contain plant pathogens but until the species is cultured and identified, its role is unknown in this case (Table 3).

Within the phylum Chytridiomycota, one identified genus was significantly higher in the Zorro fescue treatment and one was higher in the Triticale mulch treatment. *Rhizophydium* also had a non-significant trend towards higher abundance in the clover treatment (P=0.065). Some species of *Rhizophydium* are known to be plant pathogens. Within the phylum Neocallimastigomycota, there was a trend towards increased abundance of genus *Anaeromyces* in the Triticale mulch treatment. *Anaeromyces* is an anaerobic fungus generally found in ruminant animals (Table 8).

Correlation analysis between Nuriootpa fungal class and field data showed that the fungal abundance was often associated with factors affecting grapevine growth, although it must be remembered that correlation does not always mean causation. Within the phylum Ascomycota, fungal abundance of the classes, was associated with some viticulturally negative effects, especially within the clover treatment. Dothidiomycetes, Eurotiomycetes and Sordariomycetes increased soil Mn and decreased grape yield. Both the Eurotiomycetes and Sordariomycetes were associated with decreased cane numbers. The abundance of Sordariomycetes was linked with a decrease in juice tartaric acid in the clovers, while Leotiomycetes was associated with decreased juice Brix in control treatments (Table 9).

Some members of Ascomycota had positive viticultural effects. Some members of the class Chytridiomycetes were linked to an increased yield: pruning weight ratio. An unknown member of Ascomycota (C16), most abundant in the Zorro fescue and the medic treatments, was associated with an increased juice YAN, but also with a decreased soil total N (Table 9).

Within the phylum Basidiomycota, Microbotryomycetes associated with the medic treatment was linked with decreased soil pH (water) in shallow soil, decreased juice tartaric acid (medics), and increased juice ammonia content. The Pucciniomycetes, Leotiomycetes and Agaricomycetes were associated with increased soil Colwell P, especially in the control treatments. Agaricomycetes was also associated with decreased juice Brix (Table 9).

An unknown class within Blastocladiomycota was associated with increased soil Mn and decreased yield, especially within the clovers treatment. An unidentified member of Glomeromycota (C31), was linked with increased soil total carbon and total nitrogen, especially within the medic treatment (Table 9).

Correlation analysis between fungal genus and field data showed that at this level the fungal abundance was often associated with factors affecting grapevine growth. It is very interesting

that a large proportion of the genera were unknown, and the abundance of the combined fungal unknowns (C333) were found to be associated with increased petiole weight (Table 10).

Decreased berry weight was associated with *Protomyces*. Some species of *Protomyces* are plant pathogens. Decreased cane growth was also linked with possible plant pathogens, *Paraconiothyrium*, *Cryptovalsa*, *Embellisia*, and an unidentified genus in Agaricales. Decreased yields were linked with possible plant pathogens *Embellisia, Haemonectria* and *Nectria. Embellisia, Fusarium* and *Cryptovalsa* were also associated with decreased petiole weight. *Fusarium* was linked with increased yield: pruning weights, even though this genus is often plant pathogenic (Table 10).

Table 8: Fungi level 6 (Genus) in grapevine rhizosphere, Nuriootpa soil, Spring 2016. Genus names provided below table.

Treatment	**C177**	**C181**	**C215**	**C289**	**C299**	**C300**	**C304**	**C305**	**C311**	**C316**	**C326**
1 Triticale mulch	0.00004	0.00017 b	0.0327 a	0.00012	0.00002	0.000011 b	0 a	0.00008	**0.04125 a**	0.0003	**0.00184**
4 Zorro fescue	**0**	0.00017 b	0.0064 a	**0.00802**	0.00002	**0.00756 a**	**0.00371 a**	0.00008	0.0038b	0.0003	0 a
6 Angel /Sultan medic	0.00009	0.00004 b	0.0017 a	0.00117	0.00014	0.000022 b	0.00002 a	0.00011	0.00004 b	0.0001	0 a
9 Mintaro sub-clover/ Prima gland clover	**0.00307**	**0.05715 a**	**0.1581 a**	0	**0.00154**	0 b	0.00125 a	0.00133	0.00020 b	0	0.000159 a
10 Control (herbicide)	0	0.00029 b	0.0027 a	0.00008	0	0 b	0.00023 a	0.00004	0.00124 b	0.0006	0.000104 a
Mean	0.00065	0.01156	0.0403	0.00185	0.00034	0.001517	0.00103	0.00033	0.00931	0.0002	0.000419
P [1]	0.035	0.005	0.021	**0.011**	0.030	0.003	0.056	0.065	0.002	0.755	0.014
l.s.d.	0.0011	0.00310	0.03445	0.00093	0.000479	0.000281 4	0.00214 1	0.00088	0.00065	0.008	0.00027

[1]Bonferroni multiple test with a significance cut off value of 0.05

C177 Sordariomycetes; o__Hypocreales; f__Nectriaceae; g_**Volutella**

C181 Sordariomycetes; o__Hypocreales; f__unidentified; g__unidentified

C215 Sordariomycetes; o__Xylariales; f__Amphisphaeriaceae; **Truncatella**

C289 Basidiomycota; c__Tremellomycetes; o__Tremellales; f__Exidiaceae; g__**Sebacina**

C299 **Blastocladiomycota**; c__unidentified; o__unidentified; f__unidentified; g__**unidentified**

C300 Chytridiomycota; c__Chytridiomycetes; o__**Chytridiales**; f__unidentified; g__**unidentified**

C304 Chytridiomycota; c__Chytridiomycetes; o__Rhizophlyctidales; f__Rhizophlyctidaceae; g__**Rhizophlyctis**

C305 Chytridiomycota; c__Chytridiomycetes; o__Rhizophydiales; f__Rhizophydiaceae; g__**Rhizophydium**

C311 **Chytridiomycot**a; c__unidentified; o__unidentified; f__unidentified; g__**unidentified**

C316 Glomeromycota; c__Glomeromycetes; o__Glomerales; f__**Claroideoglomeraceae**; g__unidentified

C326 Neocallimastigomycota; c__Neocallimastigomycetes; o__Neocallimastigales; f__Neocallimastigaceae; g__**Anaeromyces**

Table 9: Correlations between field data and abundance of grapevine rhizosphere fungal class and their association with vineyard treatments (Nuriootpa, Spring 2016).
(Five treatments: Triticale mulch, Zorro fescue, medics, clovers and herbicide control)

	Fungal Class	**Mean abundance of fungus**	**P**	**r**	**Treatment with greatest abundance**
2016 Canes/m	C7 k__Fungi; p__Ascomycota; c__Eurotiomycetes	0.000413	0.006	-0.88	Clovers
	Abundance of fungal Class (mainly in Clovers) associated with decreased number of canes in 2016.	**0.04%**			
2017 Canes/m	C14 k__Fungi; p__Ascomycota; c__Sordariomycetes	0.160	0.048	-0.70	Clovers
	Abundance of fungal Class (mainly in clovers) associated with decreased number of canes in 2017.	16%			
2016 Yield: pruning weight ratio canes	C28 k__Fungi; p__Chytridiomycota; c__Chytridiomycetes	0.00313	<0.001	+0.94	Zorro
	Abundance of fungal Class (mainly in Zorro) associated with increased yield to pruning weight.	**0.3%**			
Soil pH (water) (0-10 cm)	C21 k__Fungi; p__Basidiomycota; c__Microbotryomycetes	0.000045	0.013	-0.83	Medics
	Abundance of fungal Class (mainly in Medics) associated with decreased soil pH (water) in shallow soil	**0.005%**			
2017 Soil Mn	C6 _Fungi; p__Ascomycota; c__Dothideomycetes	0.0388	0.018	+0.80	Clovers
	C7 k__Fungi; p__Ascomycota; c__Eurotiomycetes	0.000413	0.015	+0.82	Clovers
	C14 k__Fungi; p__Ascomycota; c__Sordariomycetes	0.160	0.006	+0.87	Clovers
	C27 k__Fungi; p__Blastocladiomycota; c__unidentified	0.000336	0.005	+0.89	Clovers
	Abundance of fungal Class (mainly in Clovers) associated with increased soil Mn	**20%**			
2016 Tartaric acid	C14 k__Fungi; p__Ascomycota; c__Sordariomycetes	0.160	0.101	-0.58	Clovers
	Abundance of fungal Class (mainly in Clovers) associated with decreased TA	**16%**			
2017 Tartaric acid	C21 k__Fungi; p__Basidiomycota; __Microbotryomycetes	0.000045	0.125	-0.53	Medics
	Abundance of fungal Class (mainly in Medics) associated with decreased TA	**0.005%**			

	Fungal Class	Mean abundance of fungus	P	r	Treatment with greatest abundance
2016 Yield (kg/vine)	C6 _Fungi; p__Ascomycota; c__Dothideomycetes	0.0388	0.111	-0.56	Mulch
	C7 k__Fungi; p__Ascomycota; c__Eurotiomycetes	0.000413	0.012	-0.83	Clovers
	C14 k__Fungi; p__Ascomycota; c__Sordariomycetes	0.160	0.071	-0.64	Clovers
	C27 k__Fungi; p__Blastocladiomycota; c__unidentified	0.000336	0.027	-0.77	Clovers
	Abundance of fungal Class (mainly in clovers) associated with decreased yield. (Note: same cohort with increased soil Mn)	**20%**			
2016 Earthworms	C16 k__Fungi; p__Ascomycota; c__unidentified	0.160	0.001	+0.93	Zorro & Medics
	Abundance of fungal Class (mainly in Zorro and Medics) associated with increased earthworms	**0.03%**			
2017 Soil total_C (%)	C31 k__Fungi; p__Glomeromycota; c__unidentified	0.00012	0.028	+0.76	Medics
	Abundance of fungal Class (mainly in Medics) associated with increased soil total carbon.	0.01%			
2017 Soil total_N (%)	C31 k__Fungi ; p__Glomeromycota; c__unidentified	0.00012	0.013	+0.83	Medics
	Abundance of the fungal Class (mainly in Medics) associated with increased soil total nitrogen.	**0.01%**			
2017 Soil total_N (%)	C16 k__Fungi; p__Ascomycota; c__unidentified	0.058	0.063	-0.66	Zorro & Medics
	Abundance of the fungal Class (mainly in Zorro and Medics) associated with decreased soil total nitrogen	**5.8%**			
2017 Soil Colwell P	C22 k__Fungi; p__Basidiomycota; c__Pucciniomycetes	0.000025	0.015	+0.82	control
	C10 k__Fungi; p__Ascomycota; c__Leotiomycetes	0.0053	0.025	+0.76	Control
	C17 k__Fungi; p__Basidiomycota; c__Agaricomycetes	0.0055	0.025	+0.77	Control
	Abundance of the fungal Class (mainly in control) associated with increased soil Colwell P	**1.1%**			
2016 Juice ^{o}Brix	C10 k__Fungi; p__Ascomycota; c__Leotiomycetes	0.0053	0.033	-0.75	Control
	C17 k__Fungi; p__Basidiomycota; c__Agaricomycetes	0.0055	0.035	-0.74	Control
	Abundance of the fungal Class (mainly in control) associated with decreased juice Brix	**1.1%**			
2016 Juice YAN	C16 k__Fungi; p__Ascomycota; c__unidentified	0.000402	0.015	+0.82	Zorro & Medics
	Abundance of the fungal Class (mainly in Zorro and Medics) associated with increased juice YAN	**0.04%**			
2016 Juice NH_3	C21 k__Fungi; p__Basidiomycota; c__Microbotryomycetes	0.000045	0.002	+0.92	Medics
	Abundance of the fungal Class (mainly in Medics) associated with increased juice ammonia.	0.005%			

Table 10: Correlations between field data and abundance of grapevine rhizosphere fungal genera and their association with vineyard treatments (Nuriootpa 2016-17).
Five treatments: Triticale mulch, Zorro fescue, medics, clovers and herbicide control

	Fungal genera	**Mean abundance of fungus**	**P**	**r**	**Treatment with greatest abundance**
Soil Fe (mg/kg)1	C39 Dothideomycetes; o__Pleosporales; f__Lophiostomataceae; g__*Lophiostoma*	0.00048	0.0355	+0.74	Medics
	C198 Sordariomycetes; o__Phyllachorales; f__Phyllachoraceae; g__*Colletotrichum*	0.00017	0.0244	+0.78	Zorro & Medics
	Abundance of genera associated with increased soil Fe	**0.07%**			
Soil Fe (mg/kg)1	C185 Sordariomycetes; o__Incertae_sedis; f__Plectosphaerellaceae; g__ *Plectosphaerella*	0.0037	0.0432	-0.71	Clovers
	Abundance of genera associated with decreased soil Fe	**0.37%**			
Soil Green Tea Decomposition	C158 Sordariomycetes; o__Hypocreales; f__Clavicipitaceae; g__*Pochonia* (Biocontrol)	0.00045	0.0811	+0.62	Controls & Medics
	Abundance of genera associated with increased Green Tea Decomposition	**0.05%**			
Soil Rooibos Tea Decomposition	C91 Sordariomycetes, Sordariales, Chaetomiaceae , *Retroconis*	0.000870	0.0756	-0.63	Clover, Zorro & Medics
	C171 Sordariomycetes; o__Hypocreales; f__Nectriaceae; g__*Fusarium*	0.058	0.0191	-0.80	Clover, Zorro & Medics
	C283 Basidiomycota; c__Microbotryomycetes; o__Sporidiobolales; f__Incertae_sedis; g__*Rhodotorula*	0.000020	0.0717	-0.64	Clovers & Medics
	Abundance of genera associated with decreased Rooibos Decomposition	**5.9%**			
Soil HWC shallow	C318 Glomeromycota; c__Glomeromycetes; o__Glomerales; f__Glomeraceae; g__*Glomus*	0.000182	0.0151	+0.82	Medics
	Abundance of genera associated with increased HWC	**0.02%**			
Soil moisture (shallow)	C39 Dothideomycetes; o__Pleosporales; f__Lophiostomataceae; g__*Lophiostoma*	0.00048	0.059	-0.67	Zorro, Medics
	C198 Sordariomycetes; o__Phyllachorales; f__Phyllachoraceae; g__*Colletotrichum*	0.00017	0.0455	-0.71	Zorro, Medics
	Abundance of genera associated with decreased soil moisture (shallow)	**0.07%**			
Soil moisture (deep)	C158 Sordariomycetes; o__Hypocreales; f__Clavicipitaceae; g__*Pochonia*	0.00045	0.0204	-0.79	Control, Medics
	Abundance of genera associated with decreased soil moisture (deep)	**0.05%**			

	Fungal genera	**Mean abundance of fungus**	**P**	**r**	**Treatment with greatest abundance**
Soil moisture (deep)	C91 Sordariomycetes, Sordariales, Chaetomiaceae, g *Retroconis*	0.000870	0.0453	+0.71	Clovers, Zorro, Medics
	C229 Fungi; p__Ascomycota; c__unidentified; o__unidentified; f__unidentified; g__unidentified	0.073	0.0196	+0.80	Zorro, Medics
	Abundance of genera associated with increased soil moisture (deep)	**7.4%**			
Soil pH (water) (deep)	C86 Dothideomycetes, Pleosporales, Cheiromyces, *Cheiromyces*	0.006705	0.0777	-0.63	Mulch
	C167 Sordariomycetes; o__Hypocreales; f__Incertae_sedis; g__*Myrothecium*	0.00543	0.06	-0.67	Mulch
	C207 Sordariomycetes; o__Sordariales; f__Lasiosphaeriaceae; g__*Schizothecium*	0.01	0.0712	-0.64	Mulch
	C222 Sordariomycetes; o__ Phomatosporales f Phomatosporaceae, g *Phomatospora*	0.002	0.0704	-0.64	Mulch
	C311 Chytridiomycota; c__unidentified; o__unidentified; f__unidentified; g__unidentified	0.009307	0.0544	-0.68	Mulch
	C326 Neocallimastigomycota; c__Neocallimastigomycetes; o__Neocallimastigales; f__Neocallimastigaceae; g__*Anaeromyces*	0.000419	0.0873	-0.61	Mulch
	Abundance of genera associated with decreased soil pH (water) (deep)	**3.4%**			
Soil pH (water) (deep)	C174 Sordariomycetes; o__Hypocreales; f__Nectriaceae; g__*Nectria*	0.000067	0.096	+0.59	Clover & Control
	C318 Glomeromycota; c__Glomeromycetes; o__Glomerales; f__Glomeraceae; g__*Glomus*	0.000182	0.0217	+0.79	Medic, Control & Clover
	Abundance of genera associated with increased soil pH (water) (deep)	**0.03%**			
Soil pH ($CaCl_2$) (shallow)	C52 Dothideomycetes; o__Pleosporales; f__Pleosporaceae; g__*Embellisia*	0.00098	0.0665	+0.65	Clover & Control
	C173 Sordariomycetes; o__Hypocreales; f__Nectriaceae; g__*Haematonectria*	0.0020	0.0529	+0.69	Clover & Control
	C174 Sordariomycetes; o__Hypocreales; f__Nectriaceae; g__*Nectria*	0.000067	0.0201	+0.79	Clover & Control
	C318 Glomeromycota; c__Glomeromycetes; o__Glomerales; f__Glomeraceae; g__*Glomus*	0.000182	0.0481	+0.70	Clover Medic & Control
	C320 Glomeromycota; c__Glomeromycetes; o__Glomerales; f__Glomeraceae; g__unidentified	0.00124	0.0498	+0.70	Control & Clover
	Abundance of genera associated with increased soil pH ($CaCl_2$) (shallow)	**0.45%**			

	Fungal genera	**Mean abundance of fungus**	**P**	**r**	**Treatment with greatest abundance**
Soil EC (deep)	C86 Dothideomycetes, Pleosporales, Cheiromyces, *Cheiromyces*	0.006705	0.0022	+0.92	Mulch
	C105 Leotiomycetes; o__Helotiales; f__Helotiaceae; g__*Rhizoscyphus*	0.000398	0.0733	+0.64	Mulch
	C165 Sordariomycetes; o__Hypocreales; f__Incertae_sedis; g__*Acremonium*	0.00862	0.0026	+0.91	Mulch
	C167 Sordariomycetes; o__Hypocreales; f__Incertae_sedis; g__*Myrothecium*	0.00543	0.0008	+0.86	Mulch
	C207 Sordariomycetes; o__Sordariales; f__Lasiosphaeriaceae; g__*Schizothecium*	0.01	0.0024	+0.92	Mulch
	C222 Sordariomycetes; o__ Phomatosporales f Phomatosporaceae, g *Phomatospora*	0.002	0.0024	+0.92	Mulch
	C311 Chytridiomycota; c__unidentified; o__unidentified; f__unidentified; g__unidentified	0.009307	0.0055	+0.88	Mulch
	C326 Neocallimastigomycota; c__Neocallimastigomycetes; o__Neocallimastigales; f__Neocallimastigaceae; g__*Anaeromyces*	0.000419	0.0019	+0.92	Mulch
	Abundance of genera associated with increased soil EC (deep soil)	**4.3%**			
Soil Mn	C47 Dothideomycetes; o__Pleosporales; f__Pleosporaceae; g__*Alternaria*	0.02917	0.0493	+0.70	Clovers
	C58 Dothideomycetes; o__Pleosporales; f__Pleosporaceae; g__unidentified	0.000074	0.007	+0.87	Clovers
	C65 Eurotiomycetes; o__Chaetothyriales; f__Herpotrichiellaceae; g__*Cladophialophora*	0.00019	0.007	+0.87	Clovers
	C90 Incertae_sedis; o__Incertae_sedis; f__Incertae_sedis; g__*Phaeoisaria*	0.001829	0.0065	+0.87	Clovers
	C153 Sordariomycetes; o__Hypocreales; f__Bionectriaceae; g__*Bionectria* (*Clonostachys*)	0.00397	0.0231	+0.78	Clovers
	C156 Sordariomycetes; o__Hypocreales; f__Clavicipitaceae; g__*Cordyceps*	0.000074	0.007	+0.87	Clovers
	C159 Sordariomycetes; o__Hypocreales; f__Clavicipitaceae; g__unidentified	0.000094	0.0033	+0.90	Clovers
	C168 Sordariomycetes; o__Hypocreales; f__Incertae_sedis; g__*Stachybotrys*	0.000022	0.007	+0.87	Clovers
	C171 Sordariomycetes; o__Hypocreales; f__Nectriaceae; g__*Fusarium*	0.058	0.0431	+0.71	Clovers
	C185 Sordariomycetes; o__Incertae_sedis; f__Plectosphaerellaceae; g__*Plectosphaerella*	0.0037	0.032	+0.75	Clovers

	Fungal genera	**Mean abundance of fungus**	**P**	**r**	**Treatment with greatest abundance**
Soil Mn cont.	C215 Sordariomycetes; o__Xylariales; f__Amphisphaeriaceae; g__*Truncatella*	0.04030	0.0128	+0.83	Clovers & Medics
	C221 Sordariomycetes; o__Xylariales; f__Incertae_sedis; g__*Monosporascus*	0.0000074	0.007	+0.87	Clovers
	C225 Sordariomycetes; o__Xylariales; f__Xylariaceae; g__unidentified	0.000015	0.007	+0.87	Clovers
	C249 Basidiomycota; c__Agaricomycetes; o__Agaricales; f__Strophariaceae; g__*Psilocybe*	0.000089	0.007	+0.87	Clovers
	C299 Blastocladiomycota; c__unidentified; o__unidentified; f__unidentified; g__unidentified	0.000344	0.0025	+0.91	Clovers
	C305 Chytridiomycota; c__Chytridiomycetes; o__Rhizophydiales; f__Rhizophydiaceae; g__*Rhizophydium*	0.000328	0.0029	+0.91	Clovers
	C307 Chytridiomycota; c__Chytridiomycetes; o__Spizellomycetales; f__Spizellomycetaceae; g__*Powellomyces*	0.000015	0.007	+0.87	Clovers
	C317 Glomeromycota; c__Glomeromycetes; o__Glomerales; f__Glomeraceae; g__*Funneliformis*	0.000151	0.0259	+0.77	Clovers
	C321 Glomeromycota; c__Glomeromycetes; o__Paraglomerales; f__Paraglomeraceae; g__*Paraglomus*	0.000007	0.007	+0.87	Clovers
	C172 Sordariomycetes; o__Hypocreales; f__Nectriaceae; g__*Gibberella*	0.00162	0.0028	+0.91	Clovers
	Abundance of genera associated with increased soil Mn	**14%**			
Petiole DW (g)	C52 Dothideomycetes; o__Pleosporales; f__Pleosporaceae; g__*Embellisia*	0.00098	0.0306	-0.75	Clovers
	C171 Sordariomycetes; o__Hypocreales; f__Nectriaceae; g__*Fusarium*	0.058	0.0234	-0.78	Clovers
	C182 Sordariomycetes, Diatrypaceae, Xylariales, *Cryptovalsa*	0.00040	<0.001	-0.98	Clovers, Zorro & Medics
	Abundance of genera associated with decreased petiole DW	**5.9%**			
Petiole DW (g)	C333 combined all fungal unknowns	0.607	0.0475	+0.70	Control, Medics & Mulch
	Abundance of genera associated with increased petiole DW	**60.7%**			

	Fungal genera	**Mean abundance of fungus**	**P**	**r**	**Treatment with greatest abundance**
Juice Malic acid	C34 Dothideomycetes; o__Pleosporales; f__Didymellaceae; g__*Phoma*	0.00291	0.0265	-0.77	Medics & Clover
	C91 Sordariomycetes, Sordariales, Chaetomiaceae, *Retroconis*	0.000870	0.0284	-0.76	Medics, Clover & Zorro
	Abundance of genera associated with decreased juice malic acid	**0.38%**			
Juice Tartaric acid	C45 Dothideomycetes; o__Pleosporales; f__Phaeosphaeriaceae; g__*Phaeosphaeria*	0.000015	0.0477	-0.70	Medics
	C240 Basidiomycota; c__Agaricomycetes; o__Agaricales; f__Hygrophoraceae; g__unidentified	0.000028	0.0405	-0.72	Medics
	C282 Basidiomycota; c__Microbotryomycetes; o__Leucosporidiales; f__Leucosporidiaceae; g__*Mastigobasidium*	0.000005	0.0477	-0.70	Medics
	C323 Glomeromycota; c__unidentified; o__unidentified; f__unidentified;g__unidentified	0.00010	0.0435	-0.71	Medics
	Abundance of genera associated with decreased juice tartaric acid	**0.02%**			
Yield (kg/vine)	C52 Dothideomycetes; o__Pleosporales; f__Pleosporaceae; g__*Embellisia*	0.00098	0.0126	-0.83	Clovers
	C173 Sordariomycetes; o__Hypocreales; f__Nectriaceae; g__*Haematonectria*	0.0020	0.0325	-0.75	Clovers, Controls
	C174 Sordariomycetes; o__Hypocreales; f__Nectriaceae; g__*Nectria*	0.000067	0.0184	-0.80	Clovers, Controls
	C251 Basidiomycota; c__Agaricomycetes; o__Agaricales; f__unidentified; g__unidentified	0.00116	0.0211	-0.79	Clovers, Controls
	C320 Glomeromycota; c__Glomeromycetes; o__Glomerales; f__Glomeraceae;g__unidentified	0.00124	0.029	-0.76	Clovers, Controls
	Abundance of genera associated with decreased yield per vine, 2017	**0.55%**			
Yield: pruning weight ratio	C171 Sordariomycetes; o__Hypocreales; f__Nectriaceae; g__*Fusarium*	0.058	0.051	+0.69	Clovers, Medics
	Abundance of genera associated with increased Yield:Pruning wt ratio	**5.8%**			
50 Berry Wt	C228 Taphrinomycetes; o__Taphrinales; f__Protomycetaceae; g__*Protomyces*	0.000356	0.0396	-0.72	Clovers
	Abundance of genera associated with decreased berry weight	**0.04%**			

	Fungal genera	Mean abundance of fungus	P	r	Treatment with greatest abundance
Canes kg/m	C41 Dothideomycetes; o__Pleosporales; f__Montagnulaceae; g__*Paraconiothyrium*	0.00053	0.0367	-0.73	Zorro, clovers
	C182 Sordariomycetes, Diatrypaceae, Xylariales, *Cryptovalsa*	0.00040	<0.001	-0.96	Clovers, Control
	Abundance of genera associated with decreased cane weight	**0.09%**			
Canes/m	C52 Dothideomycetes; o__Pleosporales; f__Pleosporaceae; g__*Embellisia*	0.00098	0.0085	-0.86	Clovers
	C251 Basidiomycota; c__Agaricomycetes; o__Agaricales; f__unidentified; g__unidentified	0.00116	0.0191	-0.80	Clovers
	Abundance of genera associated with lower cane length	**0.21%**			

Fusarium was linked with increased yield: pruning weights, even though this genus is often plant pathogenic (Table 5). *Pochonia*, species of which commonly have biological control activity, was linked with increased decomposition of green tea. *Retroconis* and *Fusarium* were linked with lower decomposition of Rooibos tea. *Pochonia, Lophiostoma* and plant pathogen *Colletotrichum* were associated with decreased soil moisture, while *Retroconis* and an unidentified Ascomycota (C229) were linked with increased soil moisture. *Lophiostoma* and *Colletotrichum* were also associated with increased soil Fe, whereas Plectosphaerella was linked with decreased Fe. *Cheoromyces, Myrothecium, Schizothecium,*and *Phomatospora* were associated with decreased soil pH, whereas *Nectria, Glomus, Embellisia* and *Haematonectria* were linked with increased soil pH. Soil EC increase was associated with *Cheiromyces, Rhizoscyphus, Acremonium, Myrothecium, Schizothecium* and *Phomatosporium* (Table 10).

Many Ascomycota were associated with increased soil Mn: *Alternaria, Cladophialophora, Phaeoisaria, Clonostachys, Cordyceps, Stachybotrys, Fusarium, Plectosphaerella, Truncatella, Monosporascus* and *Gibberella*. Reductions in juice tartaric acid were associated with *Phaeosphaeria*, while decreased malic acid was linked with *Phoma* and *Retroconis* (Table 10).

Within the Basidiomycota, an unidentified member of Agaricales was associated with decreased yield. *Rhodotorula* was associated with reduced decomposition of Rooibos tea. *Psilocybe* was linked with increased soil Mn. An unidentified genus within Blastocladiomycota (C299) was associated with increased soil Mn. Within Chytridiomycota, an unidentified genus (C311) was associated with increased soil EC, and *Rhizophydium* and *Powellomyces* were associated with increased soil Mn (Table 10).

Within Glomeromycota, *Glomus* was associated with increased Hot Water extractable Carbon (HWC). Glomus and an unidentified Glomeraceae (C320) was linked with increased soil pH. Interestingly, although Glomeraceae is usually considered beneficial to plant growth, an unknown genus within Glomeraceae (C320) was associated with decreased yield while *Funneliformis* and *Paraglomus* were linked with increased soil Mn. *Anaeromyces,* a genus within Neocallimatigomycota, was associated with decreased soil pH and increased soil EC (Table 10).

Nuriootpa bacteria

Our results showed that the bacterial communities in the grapevine rhizosphere were predominately comprised of organisms belonging to the phylum Proteobacteria (38.4%), Bacteroides (19.0%), Actinobacteria (11.4%), Acidobacteria (6.5%) and Verrucomicrobia (6.1%) (Table 11a).

Table 11a: Bacteria level 2 (Phylum) Nuriootpa rhizosphere soil, 2016

Class	Phylum	Total abundance (%)	Class	Phylum	Total abundance (%)
C5	Unclassified; Other	0.0333	C29	Bacteria; p__GOUTA4	0.00313
C27	Bacteria; p__GN02	0.0188	C30	Bacteria; p__Gemmatimonadetes	**3.14**
C28	Bacteria; p__GN04	0.00313	C32	Bacteria; p__MVP-21	0.00313
C8	Archaea; p__[Parvarchaeota]	0.0344	C33	Bacteria; p__NKB19	0.0219
C9	Bacteria; Other	0.228	C34	Bacteria; p__Nitrospirae	0.609
C10	Bacteria; p__	0.00313	C35	Bacteria; p__OD1	0.263
C11	Bacteria; p__AD3	0.00938	C36	Bacteria; p__OP11	0.0594
C12	Bacteria; p__Acidobacteria	**6.50**	C37	Bacteria; p__OP3	0.0344
C13	Bacteria; p__Actinobacteria	**11.4**	C39	Bacteria; p__Planctomycetes	**3.98**
C14	Bacteria; p__Armatimonadetes	0.278	C40	Bacteria; p__Proteobacteria	**38.4**
C16	Bacteria; p__BRC1	0.0562	C42	Bacteria; p__SR1	0.0219
C17	Bacteria; p__Bacteroidetes	**19.0**	C43	Bacteria; p__Spirochaetes	0.0437
C18	Bacteria; p__Chlamydiae	0.228	C44	Bacteria; p__TM6	0.172
C19	Bacteria; p__Chlorobi	0.209	C45	Bacteria; p__TM7	0.0875
C20	Bacteria; p__Chloroflexi	**3.60**	C47	Bacteria; p__Verrucomicrobia	**6.06**
C21	Bacteria; p__Cyanobacteria	1.00	C48	Bacteria; p__WPS-2	0.0125
C22	Bacteria; p__Elusimicrobia	0.159	C49	Bacteria; p__WS2	0.00625
C23	Bacteria; p__FBP	0.0344	C50	Bacteria; p__WS3	0.456
C25	Bacteria; p__Fibrobacteres	0.313	C51	Bacteria; p__[Thermi]	0.00938
C26	Bacteria; p__Firmicutes	1.37			

Significant differences in the bacterial community components were observed depending on the vineyard under-vine treatments. Within Archaea, Class Thaumarchaeota was highest in the wallaby grass treatment. Within Acidobacteria, classes ‘AT-s54’, Acidobacteria-6, ‘EC1113’, Chloracidobacteria and ‘iii1-8’ were highest in the Zorro fescue, wallaby grass, Zorro fescue, Zorro fescue and wallaby grass treatments, respectively. Class Rubrobacteria, within phylum Actinobacteria, was significantly higher for the clover treatment. Sphingobacteria, withion Bacteroidetes, was raised for Angel Strand/Sultan Barrel medics. Both class C0119 within Chloroflexi, and class Nostocophycideae within Cyanobacteria, were increased in the Zorro fescue treatment. Within the phylum Planctomycetes, abundance in the rhizosphere soil from class 3BR-5F was highest for wallaby grass and Zorro fescue; C6 was greatest in Triticale mulch, and Planctomycetia was highest in Zorro fescue. Within phylum Proteobacteria, class delta-Proteobacteria was highest in Zorro fescue. Triticale mulch promoted greater levels of both Absconditabacteria SR1 and class Leptospirae (within phylum Spirochaete). Classes Methylacidiphilae and Spartobacteria, members of phylum Verrucomicrobia, were both elevated with Kasbah cocksfoot (Table 11b).

Table 11b: Bacteria level 3 (Class) on grapevine rhizosphere soil, Nuriootpa, Spring 2016 [1]

Treatment	C5 Archaea; p__Crenarchaeota; c__Thaumarchaeota	C10 Archaea; p__Euryarchaeota;c Thermoplasmata	C18 Bacteria;p__Acidobacteria; c__AT-s54	C20 Bacteria; p__Acidobacteria; c__Acidobacteria-6	C23 Bacteria; p__Acidobacteria; c__DA052	C24 Acidobacteria; c__EC1113	C32 Acidobacteria; c__Chloracidobacteria	C33 Acidobacteria; c__iii1-8	C36 Actinobacteria; c__Actinobacteria	C40 Actinobacteria; c__Rubrobacteria	C54 Bacteroidetes; c__Cytophagia	C57 Bacteroidetes; c__Sphingobacteria	C71 Chloroflexi; c__C0119	C76 Chloroflexi; c__P2-11E	C85 Cyanobacteria; c__Chloroplast	C87 Cyanobacteria; c__Nostocophycideae	C100 Patescibacteria (GN02; c__3BR-5F
1 Triticale mulch	0.0145 b	0	0 b	0.0273 ab	0 a	0 b	0.0233 ab	0.00300 b	0.0613 a	0.00475 ab	0.0270 a	0.0215 b	0.00075 ab	0 a	0.0133 ab	0.00075 b	0 a
2 Kasbah cocksfoot	0.0200 b	0.00175	0 b	0.0328 ab	0 a	0.000250 b	0.0248 ab	0.00775 ab	0.0488 a	0.00575 ab	0.0290 a	0.0378 ab	0.00050 ab	0 a	0.0063 ab	0.00100 b	0 a
3 Wallaby grass (*R. geniculata*)	**0.0419 a**	0.00170	0.000021 b	**0.0348 a**	0.000353 a	0.000375 b	0.0221 ab	**0.01375 a**	0.0580 a	0.00898 ab	0.0331 a	0.0507 ab	0.00079 ab	0.000021 a	0.0085 ab	0.00122 b	**0.000353 a**
4 Zorro fescue	0.0071 b	0.00566	**0.000497 a**	0.0238 ab	0.000518 a	**0.002014 a**	**0.0394 a**	0.00703 ab	0.0483 a	0.00310 ab	0.0524 a	0.0300 b	**0.00187 a**	0 a	**0.0251 a**	**0.01150 a**	**0.000518 a**
6 Angel/ Sultan medic	0.0073 b	0.00075	0 b	**0.0123 b**	0 a	0.000250 b	0.0083 b	0.00275 b	0.0520 a	0.00150 ab	0.0427 a	**0.1095 a**	0.00025 ab	0 a	0.013 b	0.00025 b	0 a
7 Safeguard ryegrass/ Scimitar medic	0.0178 b	0.00100	0 b	0.0280 ab	0 a	0.000250 b	0.0150 ab	0.00225 b	0.0818 a	0.00500 ab	0.0703 a	0.0320 b	0 b	**0.000500 a**	0.0033 b	0.00175 b	0 a
8 Sheep fescue/ Strawberry clover	0.0095 b	0.00025	0 b	0.0288 ab	0 a	0 b	0.0228 ab	0.00575 ab	0.0785 a	0.00275 ab	0.0503 a	0.0548 ab	0.00025 ab	0 a	0.0080 ab	0.00050 b	0 a
9 Mintaro sub-clover/ Prima gland clover	0.0210 b	0.00050	0 b	0.0215 ab	0 a	0.000500 b	0.0193 ab	0.00475 ab	0.0843 a	**0.01350 a**	0.0470 a	0.0503 ab	0.00050 ab	0 a	0.0060 ab	0.00150 b	0 a
10 Control (herbicide)	0.0203 b	0.00425	0 b	0.0235 ab	0 a	**0.000750 ab**	0.0200 ab	0.00775 ab	0.0495 a	0.00100 b	0.0318 a	0.0250 b	0 b	0 a	0.0073 ab	0.00050 b	0 a
Mean	0.0177	0.00176	0.000058	0.0258	0.000097	0.000488	0.0216	0.00609	0.0625	0.00515	0.0426	0.0457	0.00055	0.000058	0.0088	0.00211	0.000097

Table 11b (cont.)

Treatment	C111 Gemmatimonadetes; c__Gemm-1	C112 Gemmatimonadetes; c__Gemm-2	C128 Microgenomates (OP11); c__unknown	C138 Planctomycetes; c__C6	C144 Planctomycetes; c__Planctomycetia	C151 Proteobacteria; c__Deltaproteobacteria	C156 Bacteria; Absconditabacteria (SR1); class: unknown	C158 Spirochaetes; c__[Leptospirae]	C174 Verrucomicrobia; c__[Methylacidiphilae]	C176 Verrucomicrobia; c__[Spartobacteria]
1 Triticale mulch	0.0153 a	0.00100 a	0 a	0.00175 a	0.0365 ab	0.0620 ab	**0.001250 a**	0.001750 a	0.00150 ab	0.0140 ab
2 Kasbah cocksfoot	0.0238 a	0.00150 a	0 a	0.00075 ab	0.0340 ab	0.0598 ab	0 ab	0.000750 abc	0.00425 a	**0.0383 a**
3 Wallaby grass (*R. geniculata*)	0.0134 a	0 a	0.000009 a	0.00033 ab	0.0351 ab	0.0482 ab	0.000059 ab	0.000024 bc	0.00209 ab	0.0210 ab
4 Zorro fescue	0.0233 a	0.00282 a	0.000530 a	**-0 .0002 b**	**0.0397 a**	**0.0691 a**	-0.000162 b	**-0.000065 c**	0.00208 ab	0.0258 ab
6 Angel/ Sultan medic	**0.048 a**	**0.00025 a**	0 a	0 ab	0.0143 b	0.0300 b	0 ab	0 bc	0.00050 b	0.0095 b
7 Safeguard Ryegrass/ Scimitar medic	0.0080 a	0.00075 a	0.000250 a	0.00025 ab	0.0370 ab	0.0573 ab	0.000250 ab	0 bc	0.00075 b	0.0200 ab
8 Sheep fescue/ Strawberry clover	0.0062 a	0.00075 a	0 a	0.00025 ab	0.0323 ab	0.0623 ab	0 ab	0 bc	0.00200 ab	0.0263 ab
9 Mintaro sub-clover/ Prima gland clover	0.0080 a	0.00075 a	0 a	0.00025 ab	0.0263 ab	0.0435 ab	0.000250 ab	**0 bc**	0.00075b	0.0168 ab
10 Control (herbicide)	0.0135 a	0.00100 a	0 a	**0 ab**	0.0238 ab	0.0300 b	0 ab	0.001000 ab	0.00200 ab	0.0165 ab
Mean	0.0129	0.00098	0.000088	0.00038	0.0310	0.0513	0.000183	0.000384	0.00177	0.0209

[1] Significant Bonferroni multiple tests with a significance cut off value of 0.05

At Nuriootpa, the clover treatment (Mintaro sub-clover/Prima gland clover), which had been shown to produce lower grape yields, was associated with higher abundances of grapevine rhizosphere Chytridiomycetes and Dothidiomycetes, many of which are plant pathogens. clover also increased the abundance of Eurotiomycetes, including the plant pathogen *Cladophialophora* and the important trunk disease fungus *Phaeomoniella*. Although not statistically significant, the levels of Sordariomycetes also appear to be raised in the clover treatment, although a larger number of replicates may be needed to show this. Members of class Sordariomycetes identified in the rhizosphere included many plant pathogens. Correlation analysis also showed that members of the Dothidiomycetes, Sordariomycetes, Basidiomycota and one Glomeromycota were associated with decreased yield and the clover treatment caused the greatest abundance of these fungi. This possible association between plant pathogenic fungi and the clover treatment is intriguing and needs to be investigated fully.

Some fungi were correlated with other negative effects viticulturally: decreased soil pH, increased soil EC, increased soil Mn, decreased juice acidity, decreased juice Brix, increased juice VA, decreased juice YAN, and decreased yield. On the other hand, different fungi were correlated with a different cohort of fungi appear to have had positive viticultural effects. At Nuriootpa they increased soil HWC, soil Fe, soil moisture and earthworms. Various fungi also were associated with increased yield: pruning weight ratio and juice YAN.

Economics

Nordblom et al. (2018) found that gross margins varied between treatments over the two years, driven mostly by yield. There were however lower implementation costs attributed to ryegrass/medic ($99/ha) and cocksfoot ($40/ha) compared with straw ($3,000/ha amortised over four years = $750/ha) and herbicide control ($333/ha). Using historical regional yield and price figures and the results from two years of trial harvest, simulated gross revenues were determined. These did not include any potential improvements in fruit or wine quality which following further research may also be attributable to the alternative treatments.

The medic and medic ryegrass treatments are similar to the straw mulch and nearly $2,000/ha/yr better than the wallaby grass which received the lowest returns. Importantly they had 32-35% better returns than the herbicide control, which is a substantial improvement in returns for minimal effort or financial outlay (Figure 14). This outcome would suggest that growers with similar soil type, grape variety and management as the Nuriootpa trial site could realise considerable improvements in financial returns by adopting medic or medic and ryegrass under-vine cover crops. This recommendation is based on only two years of harvest data, necessitating the continued maintenance and data collection from these sites to validate this result.

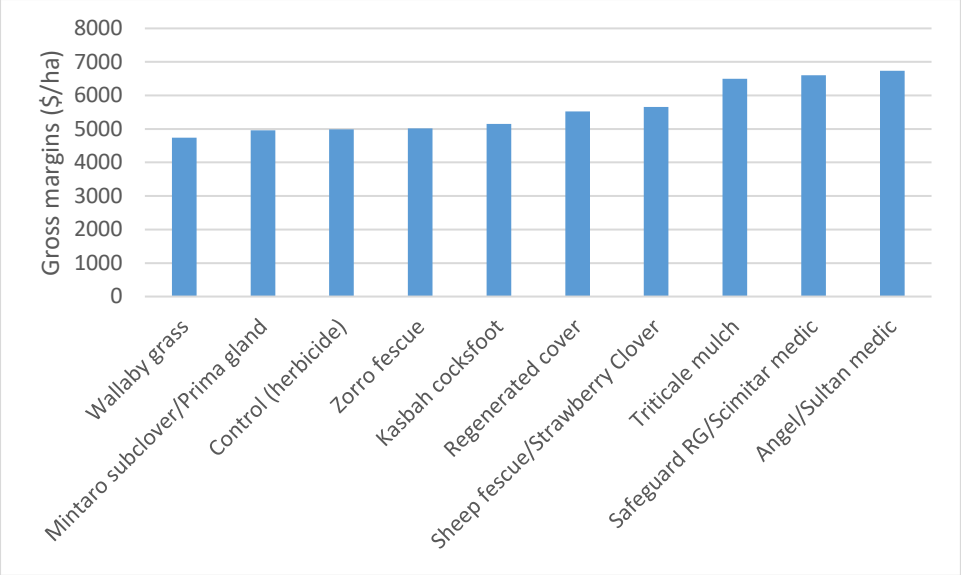


Figure 14: Simulated gross margins according to under-vine management, using known vineyard operating costs and yields from 2016 and 2017 vintages

Langhorne Creek

The Langhorne Creek vineyard, planted to Cabernet Sauvignon, is managed to produce large tonnages of C grade fruit. It is therefore imperative that any floor management treatments imposed do not adversely affect the production levels. To achieve yields of from 15 to 25 t/ha, depending on the seasons, up to 3.5 ML/ha of irrigation water is applied. The results achieved at this site have encouraged the vineyard managers to explore using the preferred treatments in a larger scale trial to ensure their fit within the management system.

Seasonal variation

While higher rainfall and lower temperatures were experienced in 2016-17, this did not translate into higher yields at this site, as shown in Figure 15. The previous year, despite a dry spring, provided above average yields at the Langhorne Creek site.

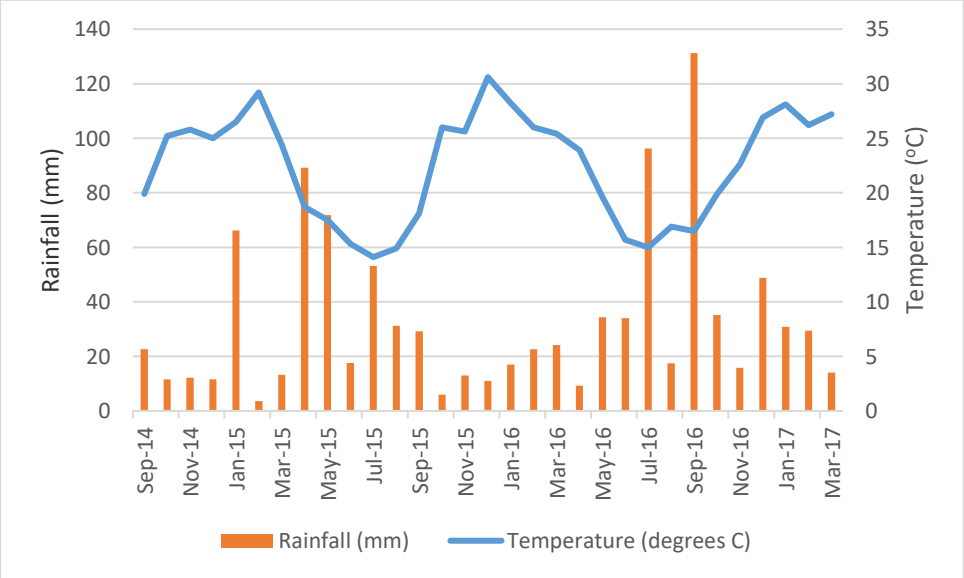
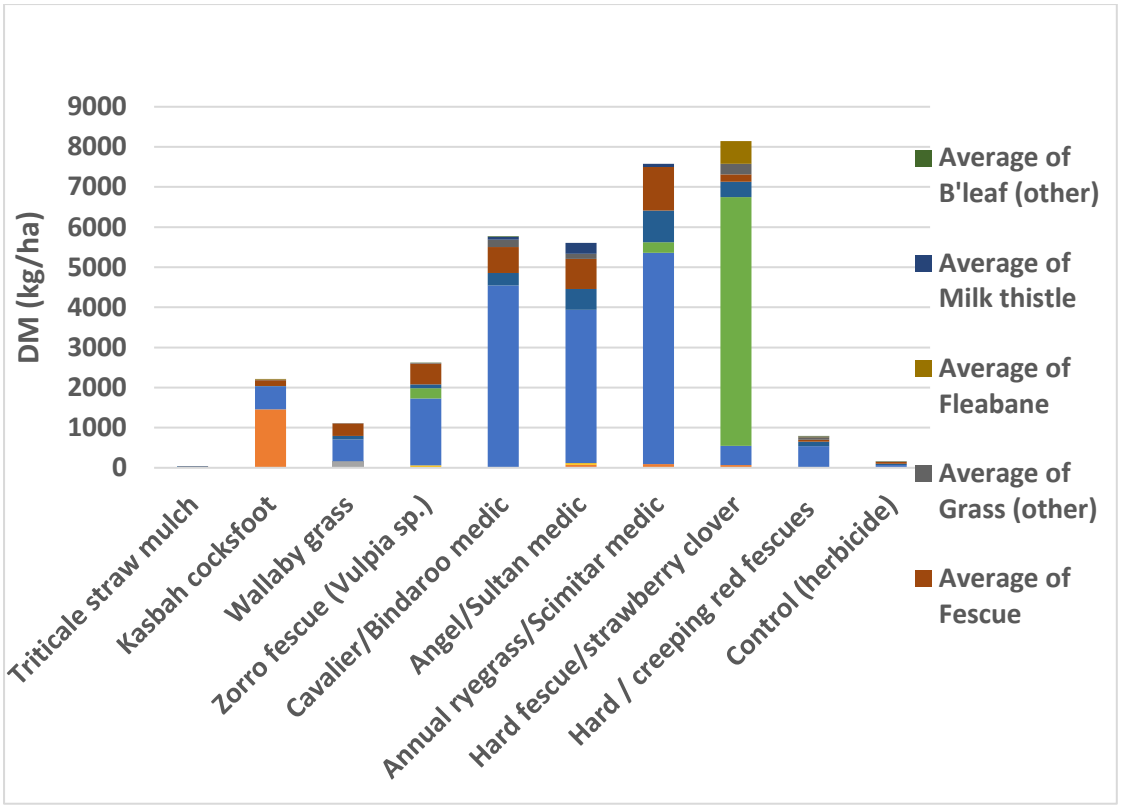


Figure 15: Monthly mean maximum temperature was lower and rainfall higher in 2016-17 than 2015/16, according to records from the Strathalbyn weather station.

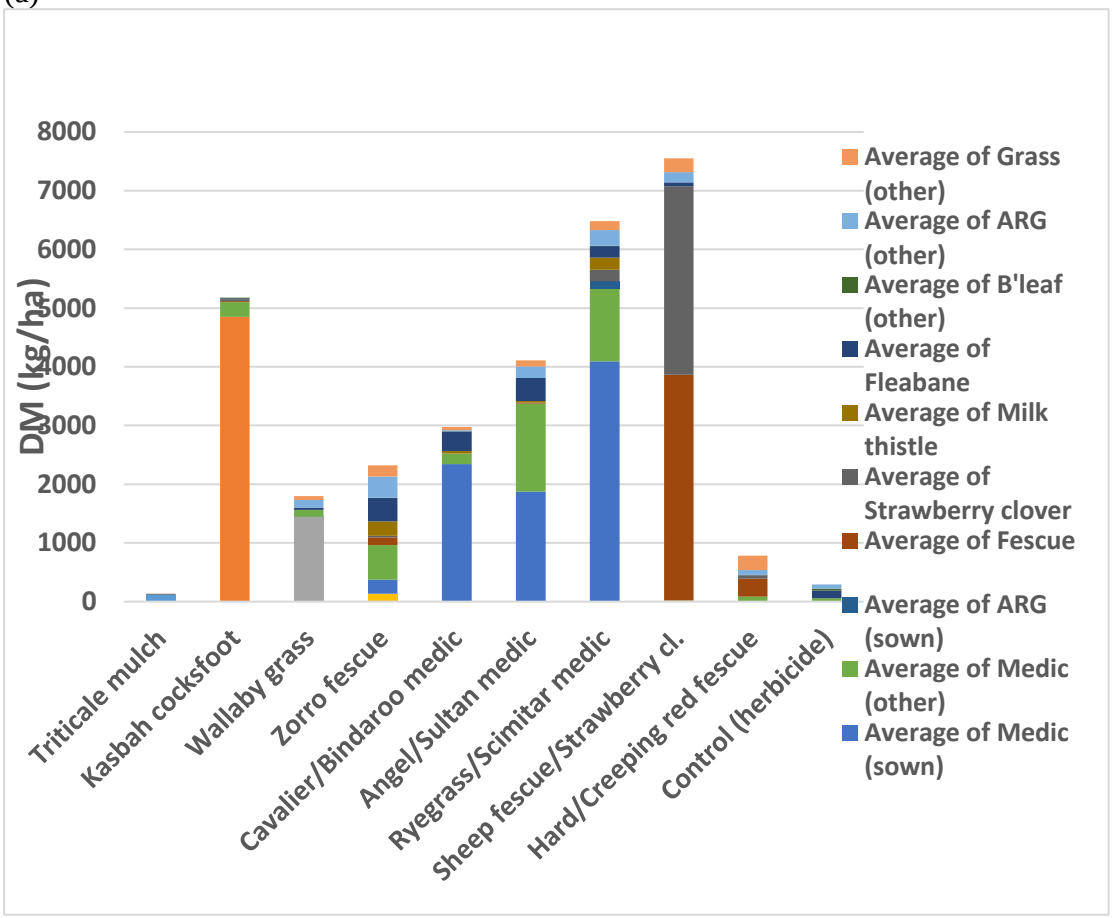
Cover crop botanical composition

This site supported impressive cover crop growth in both 2015 and 2016, as shown in Figure 16. The sandy loam topsoil which had been mounded under the vines, provided excellent tilth for establishment, and with irrigation usually starting in July the crops had plentiful moisture to grow large amounts of biomass. While the annuals senesced in spring, the site continued to support the perennials transpiring through the growing season, with visible signs of competition for water (slightly smaller canopies) but surprisingly not dramatic impacts. In both years the strawberry clover grew extremely well, but in 2017 (data not shown) the plots were dominated with fescue, which is utilising the nitrogen produced by the clover over the last two years. A succession of grasses and other nitrophilous weeds following legumes is common in temperate pastures (Medd et al., 1987). This will have tremendous benefit to soil structure, with the root system of grasses having greater mass than the legumes (Leys, 1990), and their fibrous nature aggregating the soil particles (Cockroft, 2012). It is unknown however whether in time this treatment will revert to strawberry clover as the nitrogen supply is depleted.

The wet winter and spring of 2016 provided excellent conditions for cover crop and vine growth (see Plate 2). As shown in Figure 16, very high dry matter production from the cocksfoot, ryegrass/medic and particularly the strawberry clover was achieved, highlighting their successful establishment and suitability to this site. Weed suppression was poor with the Zorro fescue, which did not perform well at this site, but all other treatments exhibited impressive competitive abilities, in particular the cocksfoot and strawberry clover treatments. Fleabane was the primary weed in the spring/summer period, and while the mulch produced on the medic treatments did not prevent its establishment, the capacity for growth was diminished. In the commercial vineyard setting, if the fleabane growth was determined to be undesirable, it could be removed with a spring knockdown herbicide application after the medic had set seed, or mown high so the medic residue is not disturbed.



(a)



(b)

Figure 16: Cover crop botanical composition and dry matter production, Langhorne Creek 2015 (a) and 2016 (b).



(a)



(b)



(c)



(d)



(e)

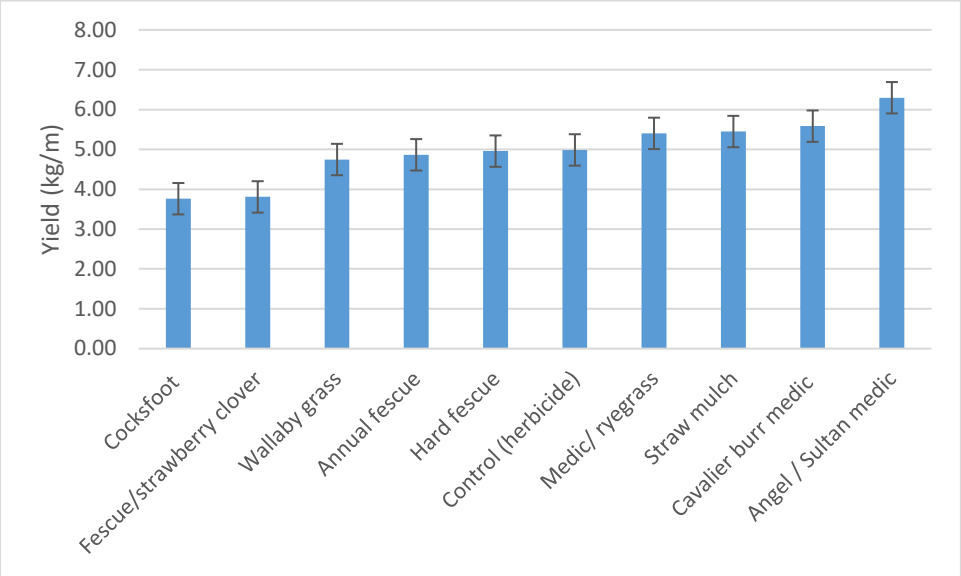
Plate 2: Under-vine cover crops at the Langhorne Creek site, 11 January 2016. (a) Angel and Sultan medic (b) wallaby grass (c) cocksfoot (d) medic and ryegrass (e) strawberry clover and hard fescue

Vine yield

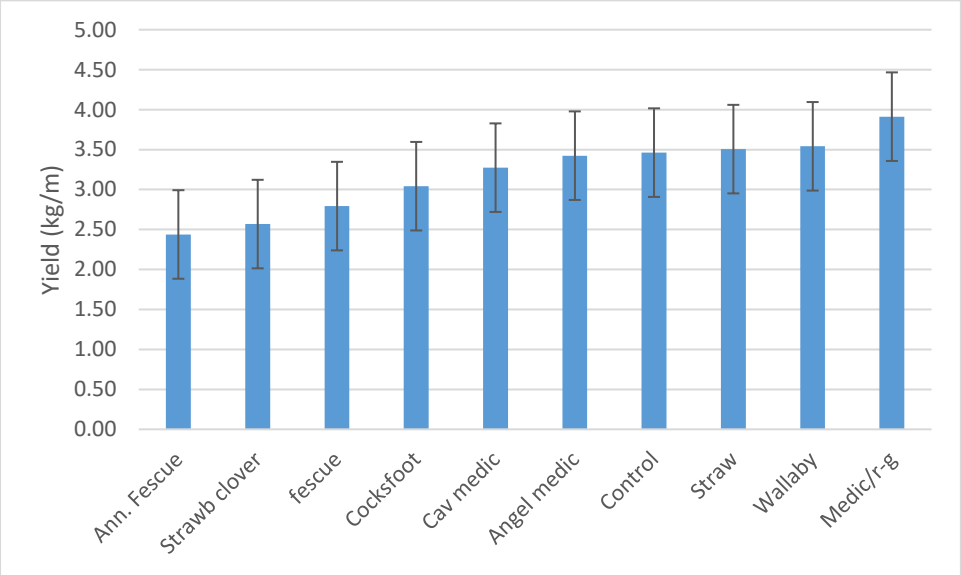
Yields over the two years varied dramatically (Figure 17), from over 25 t/ha in 2015/16 to nearly 16 t/ha in 2016/17 - a 42% yield reduction, with these figures validated by the yields achieved in the remaining commercial vineyard. Importantly across these very different years, the yields from the annual species (medics on their own or as a mix with ryegrass) were superior or similar to the herbicide control. The straw mulch also provided no significant yield benefit at this site where high rates of irrigated water application appear to override the relatively smaller evaporative losses suppressed by the straw mulch. The yield differences were driven both by berry weights and bunch numbers, with the former probably due to water stress in both the current year and at bunch initiation influencing bunch numbers.

Medic-based cover crops grew exceptionally well at this site, set large amounts of seed and there were corresponding increases in grape yield. The perennial species (cocksfoot, strawberry clover/fescue and wallaby grass) also grew very well, producing large amounts of biomass in the case of cocksfoot and strawberry clover/fescue, and to a lesser extent wallaby grass. The former two species also suppressed weeds very effectively, even excluding more obnoxious species such as fleabane and willow herb. However, the yield suppression of particularly the cocksfoot and strawberry clover treatments was excessive, with the wallaby grass equivalent to the straw and control in 2017. If producers were happy with lower yields and possibly higher quality fruit, these species may still be valuable, especially if they could be grazed over the autumn/winter period to reduce early spring biomass. They may also

respond to summer mowing as well, or a contact knockdown herbicide in spring to suppress growth, but this was not tested.



(a)



(b)

Figure 17: Harvest yields, Langhorne Creek, in (a) 2016 and (b) 2017

Petiole nutrition

Petiole N concentrations displayed a close relationship with the legume content and biomass production. Pasture legumes fix approximately 20 kg N per tonne of dry matter. As determined with the Botanal pasture measurement tool, approximately 5 t/ha of legume biomass was produced by the medic treatment. When the under-vine production is translated to the whole vineyard floor this becomes about 35 kg of nitrogen per hectare.

As the organic matter was mineralised in spring with warm soil temperatures and moist soil through applied irrigation, some of this nitrogen became available to the vine roots and was readily taken up. The grasses however were net users of nitrogen for their own growth. A

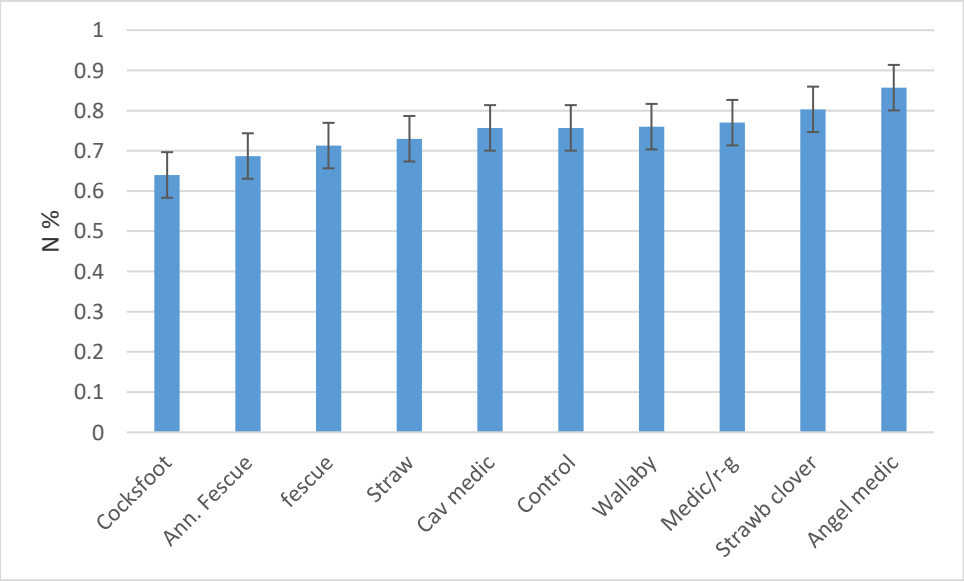
paler green colour was evident in the vine foliage of the grass treatments, and according to the standards, where 0.8–1.1% is deemed adequate tissue N (Proffitt and Campbell-Clause, 2012), vines growing on the grass treatments were in deficit.

Petiole P levels also reflected expectations. All the growing cover crops require P for growth, with legumes typically having a higher demand to the needs of rhizobium bacteria and the high protein biomass. The straw and herbicide controls however provided no competition for P, and the vines had access to luxurious supplies (the standards suggest greater than 0.5% is adequate). With these high levels in the petioles it would suggest there was also no requirement for the P to be sourced via mycorrhizae.

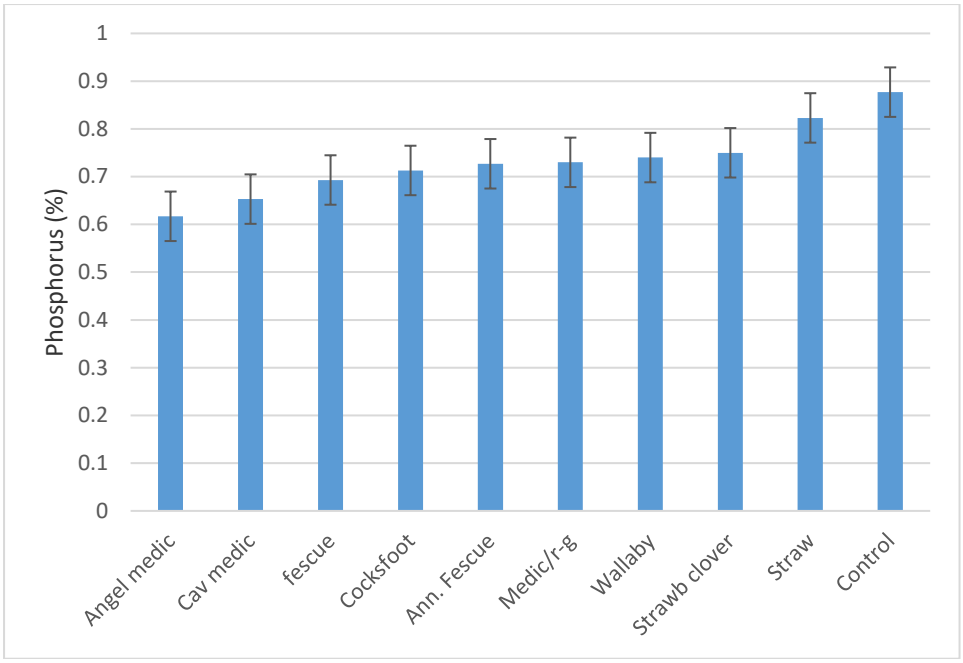
Calcium levels were adequate on all treatments, with 1.5 to 2.5% being recognised as sufficient. Calcium is also required by the rhizobia so it will be in higher demand by the legumes (which require about 0.4 kg Ca/tonne of dry matter) than the grasses. As shown in Figure 18(c), Ca levels were lower in the legume treatments, but still at adequate levels.

Petiole zinc levels were adequate (>26 mg/kg) across all treatments, but the perennial strawberry clover did show higher levels than the straw, possibly due to higher mycorrhizal infection.

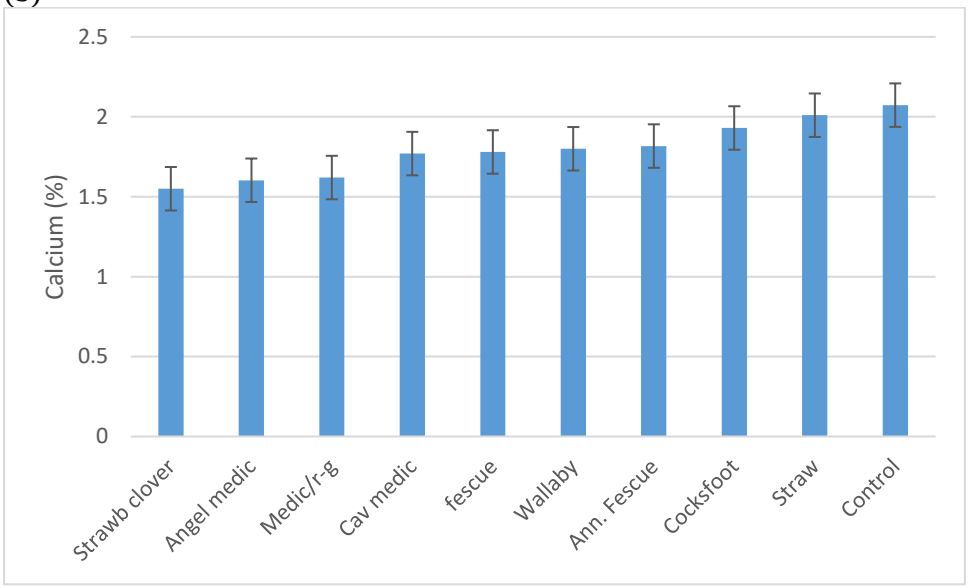
Petiole chloride was substantially higher on the legume cover crop treatments than the grasses. Californian work (Cook and Kissler, 1960) suggests levels greater than 0.5% are in excess and can affect yield. With the exception of the strawberry clover cover crop, which would have reduced yield through competition for water, the rest of the vine yields have a very strong correlation with chloride concentration, suggesting there is not an excess in this case. As noted by Wege et al. (2017), chloride is an essential plant micronutrient which at concentrations beyond micronutrient requirements can stimulate plant growth. The more legume biomass that was produced the higher the petiole chloride levels, which may also be due to an increased chloride concentration due to a drier topsoil. The cocksfoot also had high biomass but low petiole chloride so additional answers are sought as to why this has occurred. Importantly there were no apparent detrimental impacts of the higher chloride levels on yield at this site.



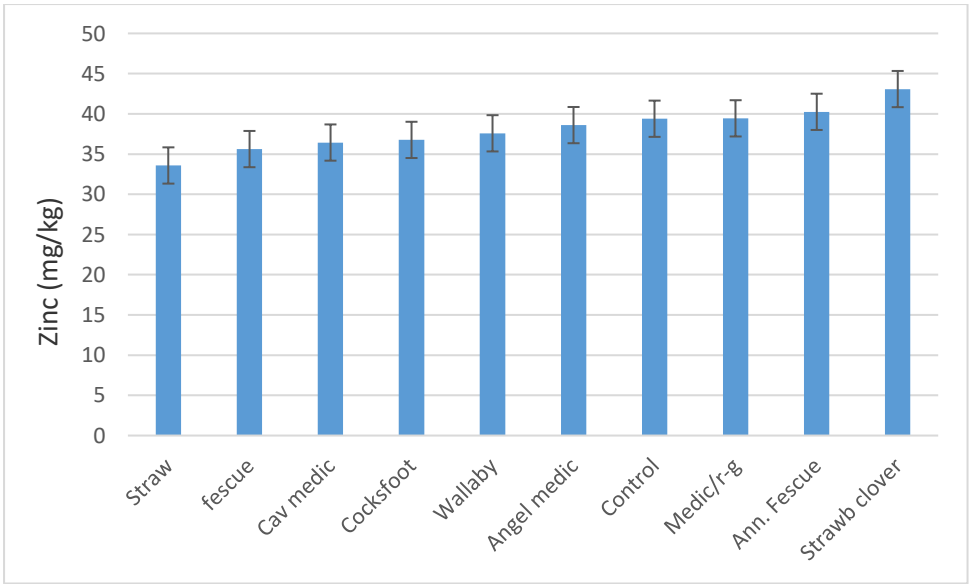
(a)


Phosphorus (%)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Angel medic
Cav medic
fescue
Cocksfoot
Ann. Fescue
Medic/r-g
Wallaby
Strawb clover
Straw
Control

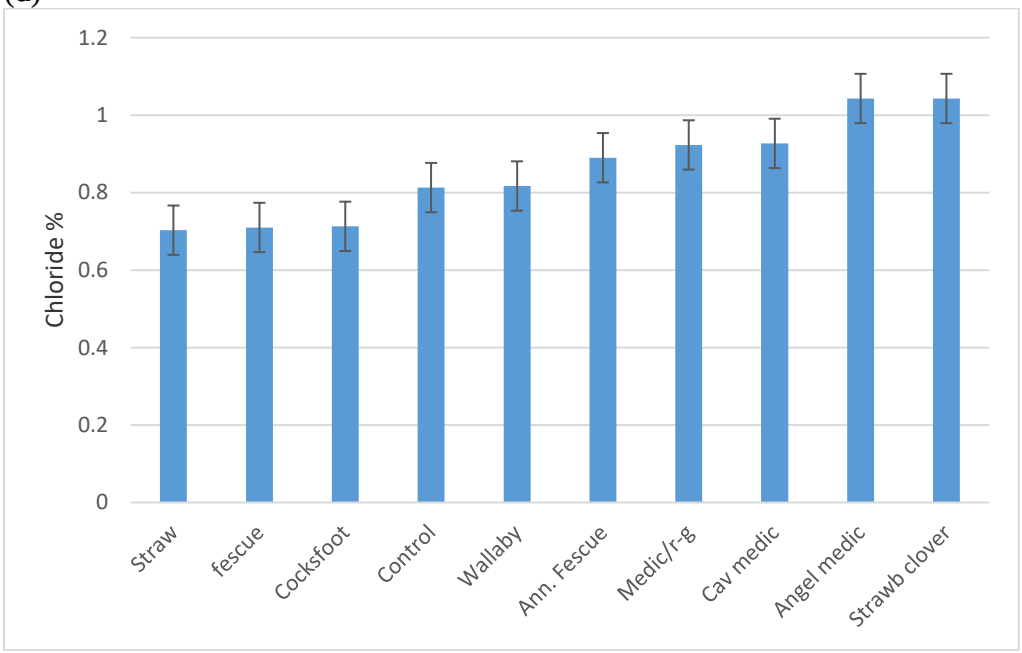
(b)


Calcium (%)
2.5
2
1.5
1
0.5
0
Strawb clover
Angel medic
Medic/r-g
Cav medic
fescue
Wallaby
Ann. Fescue
Cocksfoot
Straw
Control

(c)



(d)



(e)

Figure 18: Petiole nutrient concentrations from Langhorne Creek vines (2016) where significant differences were apparent: nitrogen (a), phosphorus (b), calcium (c), zinc (d) and chloride (e).

Fruit quality and vine responses

In the drier 2015/16 vintage, vine leaf area (LAIe) was significantly higher in the straw treatment, where the mulch was able to buffer periods of moisture stresses imposed in that season. With the wet conditions in 2016/17 there was no advantage in having the straw mulch nor any other treatment in developing larger canopies.

The main drivers of yield in 2015/16 were bunch weights but in the 2016/17 season berry weights were important, with those cover crop treatments providing the greatest competition for water through active growth over summer also having the lowest berry weights.

Brix levels showed significant differences in both years, but their range from lowest to highest was very small. Titratable acidity also showed a small but significant result in 2017, being highest on the straw treatment and lowest on Cavalier medic.

Yeast Available Nitrogen showed significant differences in both years, with the legume cover crops being responsible for the highest YAN. In 2015/16 there was a strong correlation with petiole N (r^2=0.97). There was however no correlation with total soil N or C, suggesting the N available to the vines was either that which had leached down the profile and was available to the deeper roots, or was N that had mineralised over the summer growing period.

Yield to pruning weight ratios (Y:P), as shown in Figure 19, are often used as a retrospective indicator of vine balance. They correlated strongly with petiole total N and ammonia, and the ratios tended to be higher (more fruit per mass of canopy) on the legume cover crop treatments. All the ratios are within the range of 5-12 suggested by Iland et al. (2011). An unfortunate contractor error prevented cane weights from being collected in 2017.

Table 6: Vine responses and fruit quality from Langhorne Creek in (a) 2015/16 and (b) 2016/17

Treatment	LAIe	Bunches (#/m)	Bunch wt. (g)	50 Berry weight (g)	Brix	TA	pH	Petiole N (mg/L)	YAN (mg/L)	Canes (#/m)	Canes (kg/m)	Y:P (kg/kg canes)
Straw	4.0c	41.0	135.4ab	51.1	21.8c	6.4	3.16	100.8	119.8a	35.7	0.88d	6.1
Cocksfoot	2.6a	34.2	114.7a	44.5	22.3bc	6.1	3.16	114.0	136.2abc	29.5	0.49ab	7.8
Wallaby	2.9ab	38.4	127.3ab	48.8	22.2bc	6.5	3.14	94.8	118.0a	32.2	0.58bc	9.0
Ann. fescue	2.8a	37.2	135.8ab	48.9	22.1bc	6.9	3.10	99.7	126.3ab	31.9	0.57b	9.0
Cav medic	2.6ab	38.1	150.4bc	50.2	21.5ab	6.7	3.15	119.1	156.1bcd	31.5	0.53ab	10.2
Angel medic	2.9ab	36.7	176.4c	51.4	20.9a	6.8	3.09	133.2	174.2d	31.4	0.58bc	10.8
Medic/r-g	2.9ab	39.4	140.6ab	48.9	21.0a	7.0	3.10	111.4	146.3abcd	32.6	0.53bc	10.4
Strawb clover	2.6a	35.7	108.6a	40.9	22.3c	6.0	3.21	136.5	167.4cd	31.4	0.39a	10.4
Fescue	2.6a	37.1	134.9ab	48.1	21.8b	6.7	3.10	106.5	130.8ab	31.9	0.59bc	8.0
Control	3.2b	40.9	123.1ab	48.5	22.6c	6.6	3.13	93.4	114.2a	31.6	0.75cd	7.1
Site Mean	**2.95**	**37.9**	**134.7**	**48.1**	**21.86**	**6.6**	**3.1**	**111.0**	**138.9**	**31.98**	**0.5916**	**8.89**
F pr.	**<0.001**		**0.023**		**0.001**				**0.009**		**<0.001**	**0.012**
Coefficient of variation %	**11.4**		**17.1**		**2.4**				**17.1**		**19.1**	**21**
Average LSD (P=0.05)	**0.486**	**NS**	**34.26**	**NS**	**0.78**	**NS**	**NS**	**NS**	**34.96**	**NS**	**0.166**	**2.70**

(a)

Treatment	LAIe	Bunches (#/m)	50 Berry wt. (g)	Bunch wt. (g)	Total Acid (g/L)	pH	Brix	YAN	Canes (#/m)
Straw	1.89	54.9	58.29c	35.6	7.63c	3.34	22.4abc	251ab	38.9
Cocksfoot	1.82	51.0	49.67ab	35.8	6.8b	3.56	22.6bc	219a	35.7
Wallaby	1.68	58.8	51.69ab	36.4	6.85b	3.46	22.5abc	256b	36.9
Ann. fescue	2.05	51.0	51.52ab	30	6.7b	3.45	22.9c	279bc	31.6
Cav medic	1.73	61.5	53.6 bc	30	5.88a	3.60	21.8a	279bc	40.5
Angel medic	1.79	62.9	53.24b	32.1	6.33ab	3.51	21.9ab	291c	37.2
Medic/r-g	1.62	55.9	52.64b	43.6	6.5ab	3.51	21.9abc	278bc	40.2
Strawb clover	1.96	54.4	47.06a	29.2	6.45a	3.53	22.2abc	306c	34.9
Fescue	1.73	57.4	54.65ab	27	6.53ab	3.50	22.9c	225a	36.1
Control	1.98	56.2	51.38ab	38.7	6.55ab	3.48	22.4abc	278bc	36.4
Site Mean	**1.83**	**56.4**	**52.4**	**33.8**	**6.62**	**3.50**	**22.36**	**267**	**36.8**
F pr.			**0.028**	**0.07**	**0.011**	**0.052**	**0.045**	**<0.001**	
CV%			**6.5**		**7.7**		**2.4**	**8.9**	
Ave. LSD (P=0.05)	**NS**	**NS**	**5.08**	**NS**	**0.75**	**NS**	**0.769**	**34.8**	**NS**

(b)

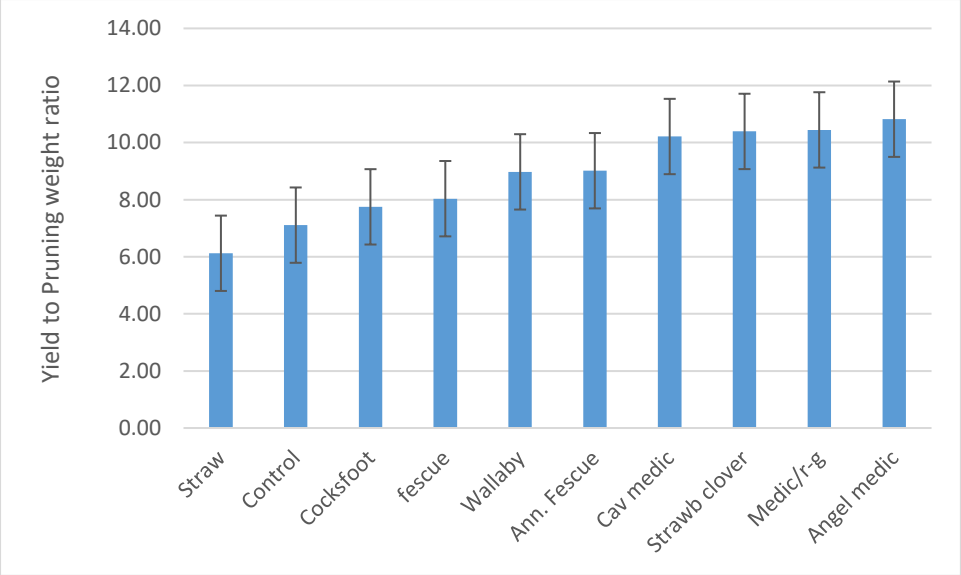


Figure 19: Yield to pruning weight ratios in 2015/16 were significantly different between controls and legume treatments

Soil properties

Figure 20 shows what can be achieved in improved soil carbon and nitrogen over a relatively short time by the introduction of under-vine cover crops. This is a very impressive result, given the short time frame, and was achieved in one treatment (medic and ryegrass) without compromising fruit yields. It was also achieved for a cost of less than $200/ha (seed plus seeding), which is considerably cheaper than the importation of compost that would be required to achieve the same result. The 26% increase in carbon witnessed on the medic/ryegrass treatment represents 3.8 t/ha of additional carbon in the top 10 cm of soil, and there would have been more added from roots and associated micro-organisms further down the soil profile.

The correlation shown between carbon and nitrogen shows the balance that is naturally maintained in the soil between these two elements. About a 10:1 ratio is generally required, so as carbon levels increase, so must the soil nitrogen. High carbon treatments such as the straw do not have the nitrogen to enable this balance to be maintained, so the carbon does not increase. The legume cover crops supply large amounts of N, but it seems to be also important to have the grass component in the mix, with root and leaf tissue that is not so readily mineralised.

Despite differences of over 100% in soil phosphorus, they were not significantly different, and no trend was apparent between treatments.

With regard to soil micronutrients, manganese levels were substantially higher on the strawberry clover treatment and zinc was higher on all those treatments containing grasses, the latter possibly due to their fibrous root system being more effective at accessing this nutrient.

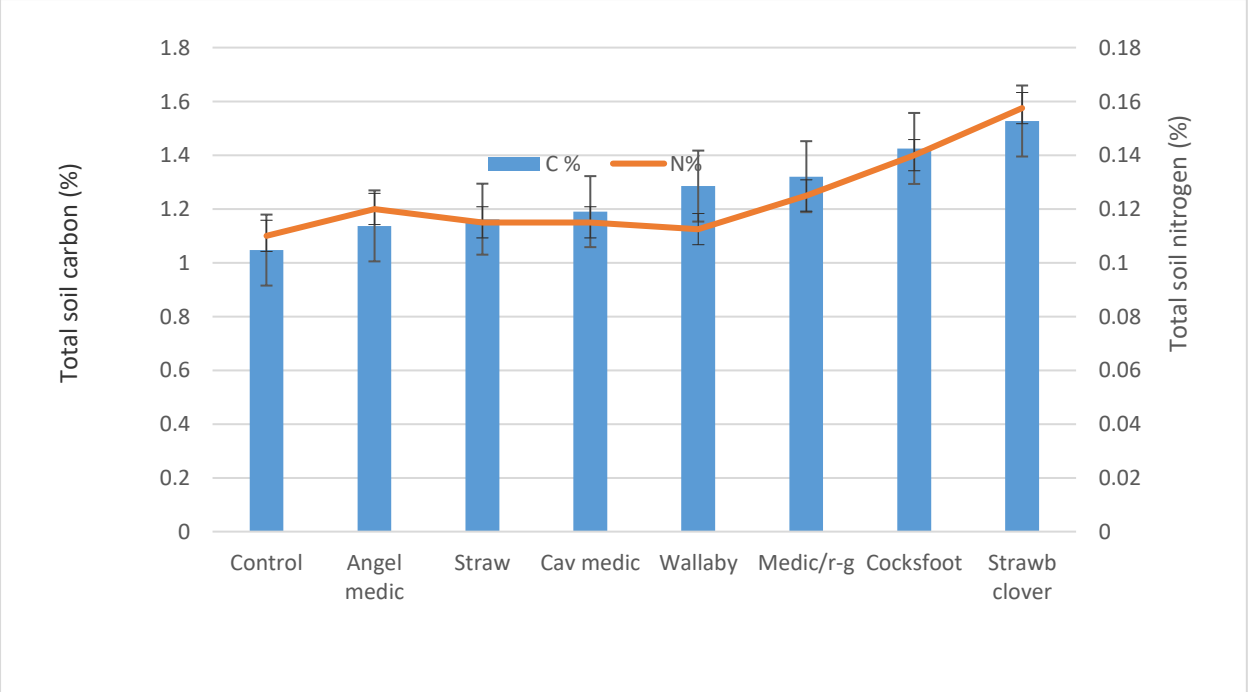


Figure 20: Soil total carbon and nitrogen following three years of under-vine cover cropping, Langhorne Creek, 2017.

Soil biology

Our results provide evidence that the Langhorne Creek rhizosphere grapevine fungal community was, in similarity with Nuriootpa, composed primarily of an unidentified class within phylum Zygomycetes (63.7% abundance). The next highest abundance was Sordariomycetes within phylum Ascomycota (16.2%) (Table 7a). There were some significant differences between the grapevine rhizosphere populations of different vineyard treatments. At the Class level, the wallaby grass treatment was associated with higher abundances of Chytridiomycetes and lower levels of an unidentified member of Glomeromycota (Table 7b).

Correlation analysis between fungal class and field data showed that, similarly to Nuriootpa, the fungal abundance was often associated with factors affecting grapevine growth. Increased soil Colwell P (readily available for plant growth) was associated with Archaeorhizomycetes and Eurotiomycetes. Unidentified classes in Basidiomycota and Blastocladiomycota were linked with both increased Colwell P and EC in deep soil. Cystobasidiomycetes, Eurotiomycetes and Basidiomycota were associated with increased EC in shallow soil (Table 8). Increased soil Fe was associated with Saccharomycetes, Chytridiomycetes and an unidentified Chytridiomycota. An unidentified Glomeromycota was linked with increased soil Fe.

Decomposition of Green tea and Rooibos tea was decreased by Leotiomycetes and Pezizomycetes and a Chytridiomycota, respectively. A Saccharomycetes and unknown Chytridiomycota were associated with increased soil HWC. In contrast to Nuriootpa, only one class, unknown Chytridiomycota, increased soil Mn. Increased soil moisture was associated with Sordariomycetes and Dothideomycetes, whereas Eurotiomycetes was linked with decreased soil moisture. Decreased soil pH was associated with an unknown Blastocladiomycota, unknown Basidiomycota, Cystobasidiomycetes, Eurotiomycetes and Archaeorhizomycetes. Increased soil total C was linked with Chytridiomycetes, unknown Chytridiomycota and unknown Zygomycota. Increased soil total N was associated with

Chytridiomycetes and unknown Chytridiomycota. Increased juice Baumé and Brix were associated with Dothideomycetes, an unknown Basidiomycota, Dothideomycetes and Archaeorhizomycetes. Both malic acid and tartaric acid increases were associated with Chytridiomycota and Zygomycota. Increased juice TSS was linked with Archaeorhizomycetes and an unknown Ascomycota. Increased total acid was associated with Saccharomycetes, and unknown Asomycota and Zygomycota. Dothideomycetes and Sordariomycetes were associated with increased VA and YAN respectively. On the other hand, Chytridiomycota were linked with decreased YAN. Regarding vine growth, reduced bunch numbers were associated with Eurotiomycetes and Chytridiomycetes, increased crown porosity with Blastocladiomycota and decreased yield with Archaeorhizomycetes (Table 8).

Table 7a: Fungi level 3 (Class) Langhorne Creek rhizosphere soil 2016

Order		Total abundance (%)
C5	Ascomycota;c__Archaeorhizomycetes	0.256
C6	Ascomycota;c__Dothideomycetes	**1.91**
C7	Ascomycota;c__Eurotiomycetes	0.100
C8	Ascomycota;c__Incertae_sedis	**4.07**
C10	Ascomycota;c__Leotiomycetes	**1.78**
C11	Ascomycota;c__Orbiliomycetes	0.0572
C12	Ascomycota;c__Pezizomycetes	0.312
C13	Ascomycota;c__Saccharomycetes	0.00255
C14	Ascomycota;c__Sordariomycetes	**16.2**
C16	Ascomycota;c__unidentified	**2.27**
C17	Basidiomycota;c__Agaricomycetes	**1.07**
C19	Basidiomycota;c__Cystobasidiomycetes	0.00305
C21	Basidiomycota;c__Microbotryomycetes	0.00927
C23	Basidiomycota;c__Tremellomycetes	**3.95**
C25	Basidiomycota;c__unidentified	0.601
C27	Blastocladiomycota;c__unidentified	0.0697
C28	Chytridiomycota;c__Chytridiomycetes	**1.52**
C29	Chytridiomycota;c__unidentified	0.0163
C30	Glomeromycota;c__Glomeromycetes	0.570
C31	Glomeromycota;c__unidentified	0.135
C34	Zygomycota;c__Incertae_sedis	**1.41**
C36	Zygomycota;c__unidentified	**63.7**

Table 7b: Abundances fungi level 3 (Class) Langhorne Creek, 2016-17

	Abundance (%)	
Treatment	C28 k__Fungi; p__Chytridiomycota; c__Chytridiomycetes	C31 k__Fungi; p__Glomeromycota; c_unidentified
Kasbah cocksfoot	2.67 ab	0.280 a
Wallaby grass	5.37 a	0 b
Angel/Sultan medic	0 b	0.265 a
Control (herbicide)	0 b	0.224 a
	1.54	0.100
P	0.032	0.028
l.s.d.	0.03395	0.3198

Table 8: Correlations between field data and abundance of grapevine rhizosphere fungal classes (level 3) and their association with vineyard treatments (Langhorne Creek, 2016-17). Four treatments: Kasbah cocksfoot, wallaby grass, medics, and control (regenerated)

		Mean abundance (%)	**P**	**r**
Soil Colwell P	C5 k__Fungi; p__Ascomycota; c__Archaeorhizomycetes	0.17	0.029	+0.71
	C7 k__Fungi; p__Ascomycota; c__Eurotiomycetes	0.072	0.012	+0.79
	C25 k__Fungi; p__Basidiomycota; c__unidentified	0.56	<0.001	+0.92
	C27 k__Fungi; p__Blastocladiomycota; c__unidentified	0.072	0.030	+0.71
	Abundance of classes associated with increased soil Colwell P	0.874		
Soil Fe	C13 k__Fungi; p__Ascomycota; c__Saccharomycetes	0.0017	<0.001	+0.95
	C28 k__Fungi; p__Chytridiomycota; c__Chytridiomycetes	1.54	0.033	+0.70
	C29 k__Fungi; p__Chytridiomycota; c__unidentified	0.011	<0.001	+0.98
	Abundance of classes associated with increased soil Fe	1.5527		
Soil Cu	C31 k__Fungi; p__Glomeromycota; c__unidentified	0.100	0.042	+0.67
	Abundance of classes associated with increased soil Cu			
Soil EC (deep soil)	C27 k__Fungi; p__Blastocladiomycota; c__unidentified	0.072	0.008	+0.82
	C25 k__Fungi; p__Basidiomycota; c__unidentified	0.56	0.015	+0.77
	Abundance of classes associated with increased EC in deep soil	0.632		
Soil EC shallow	C25 k__Fungi; p__Basidiomycota; c__unidentified	0.56	0.005	+0.85
	C19 k__Fungi; p__Basidiomycota; c__Cystobasidiomycetes	0.0020	<0.001	+0.96
	C7 k__Fungi; p__Ascomycota; c__Eurotiomycetes	0.072	0.015	+0.77
	Abundance of classes associated with increased EC in shallow soil	0.634		
Soil green tea decomposition (%)	C10 k__Fungi; p__Ascomycota; c__Leotiomycetes	1.90	0.032	-0.70
	C12 k__Fungi; p__Ascomycota; c__Pezizomycetes	0.302	0.004	-0.86
	Abundance of classes associated with decreased green tea decomposition in soil	2.202		

		Mean abundance (%)	**P**	**r**
Soil Rooibos tea decomposition (%)	C29 k__Fungi; p__Chytridiomycota; c__unidentified	0.011	0.043	-0.66
	Abundance of classes associated with decreased soil Rooibos tea decomposition	0.011		
Soil HWC (shallow soil) (mg/g)	C29 k__Fungi; p__Chytridiomycota; c__unidentified	0.011	0.010	+0.80
	C13 k__Fungi; p__Ascomycota; c__Saccharomycetes	0.0017	0.002	+0.90
	Abundance of classes associated with increased HWC	0.0127		
Soil Mn	C29 k__Fungi; p__Chytridiomycota; c__unidentified	0.011	0.027	+0.72
	Abundance of classes associated with increased soil Mn	0.011		
Soil moisture (shallow) (%)	C7 k__Fungi; p__Ascomycota; c__Eurotiomycetes	0.072	0.028	-0.72
	Abundance of classes associated with decreased soil moisture in shallow soil	0.072		
Soil moisture (deep) (%)	C14 k__Fungi; p__Ascomycota; c__Sordariomycetes	16.4	0.036	+0.69
	C6 k__Fungi; p__Ascomycota; c__Dothideomycetes	1.85	0.020	+0.75
	Abundance of classes associated with increased soil moisture in deep soil	18.25		
Soil pH (water) (deep soil)	C27 k__Fungi; p__Blastocladiomycota; c__unidentified	0.072	0.028	-0.72
	C25 k__Fungi; p__Basidiomycota; c__unidentified	0.56	0.048	-0.65
	C19 k__Fungi; p__Basidiomycota; c__Cystobasidiomycetes	0.0020	0.022	-0.74
	C7 k__Fungi; p__Ascomycota; c__Eurotiomycetes	0.072	0.009	-0.81
	Abundance of classes associated with decreased pH in deep soil	0.706		
Soil pH (water) (shallow soil)	C5 k__Fungi; p__Ascomycota; c__Archaeorhizomycetes	0.17	0.024	-0.73
	C27 k__Fungi; p__Blastocladiomycota; c__unidentified	0.072	0.048	-0.65
	Abundance of classes associated with decreased pH in shallow soil	0.242		
Soil total C	C28 k__Fungi; p__Chytridiomycota; c__Chytridiomycetes	1.54	0.013	+0.78
	C29 k__Fungi; p__Chytridiomycota; c__unidentified	0.011	0.030	+0.71
	C34 k__Fungi; p__Zygomycota; c__Incertae_sedis	1.59	0.031	+0.70
	Abundance of classes associated with increased soil total C	3.141		

		Mean abundance (%)	**P**	**r**
Soil total N	C28 k__Fungi; p__Chytridiomycota; c__Chytridiomycetes	1.54	0.035	+0.69
	C29 k__Fungi; p__Chytridiomycota; c__unidentified	0.011	0.027	+0.72
	Abundance of classes associated with increased soil total N	1.551		
Juice Baumé	C5 k__Fungi;p__Ascomycota; c__Dothideomycetes	0.17	0.024	+0.73
	C25 k__Fungi; p__Basidiomycota; c__unidentified	0.56	0.044	+0.66
	Abundance of classes associated with increased juice Baumé	0.73		
Juice ^{o}Brix	C5 k__Fungi; p__Ascomycota; c__Dothideomycetes	0.17	0.027	+0.72
	C8 k__Fungi; p__Ascomycota; c__Incertae_sedis	0.037	0.044	+0.66
	C5 k__Fungi; p__Ascomycota; c__Archaeorhizomycetes	0.17	0.012	+0.79
	C25 k__Fungi; p__Basidiomycota; c__unidentified	0.56	0.031	+0.70
	Abundance of classes associated with increased juice Brix	0.937		
Juice ^{o}Brix	C11 k__Fungi; p__Ascomycota; c__Orbiliomycetes	0.057	0.047	-0.65
	C14 k__Fungi; p__Ascomycota; c__Sordariomycetes	16.4	0.042	-0.67
	Abundance of classes associated with decreased juice Brix	16.457		
Juice Malic acid	C28 k__Fungi; p__Chytridiomycota; c__Chytridiomycetes	1.54	0.006	+0.84
	C29 k__Fungi; p__Chytridiomycota; c__unidentified	0.011	0.006	+0.84
	C34 k__Fungi; p__Zygomycota; c__Incertae_sedis	1.59	0.011	+0.80
	Abundance of classes associated with increased juice malic acid			
Juice Tartaric acid (g/L)	C28 k__Fungi; p__Chytridiomycota; c__Chytridiomycetes	1.54	0.006	+0.84
	C34 k__Fungi; p__Zygomycota; c__Incertae_sedis	1.59	0.037	+0.68
	Abundance of classes associated with increased juice tartaric acid			
Juice TSS	C5 k__Fungi; p__Ascomycota; c__Archaeorhizomycetes	0.17	0.027	+0.72
Juice TSS	C8 k__Fungi; p__Ascomycota; c__Incertae_sedis	0.037	0.044	+0.66
	Abundance of classes associated with increased juice TSS			

		Mean abundance (%)	P	r
Juice total acid	C8 k__Fungi; p__Ascomycota; c__Incertae_sedis	0.037	0.048	-0.65
	C13 k__Fungi; p__Ascomycota; c__Saccharomycetes	0.0017	0.040	+0.67
	C34 k__Fungi; p__Zygomycota; c__Incertae_sedis	1.59	0.036	+0.69
	Abundance of classes associated with increased juice total acid			
Juice VA	C5 k__Fungi; p__Ascomycota; c__Dothideomycetes	0.17	0.049	+0.65
	Abundance of classes associated with increased juice VA			
Juice YAN	C14 k__Fungi; p__Ascomycota; c__Sordariomycetes	16.4	0.047	+0.65
	Abundance of classes associated with increased juice YAN			
Juice YAN	C28 k__Fungi; p__Chytridiomycota; c__Chytridiomycetes	1.54	0.029	-0.71
	C29 k__Fungi; p__Chytridiomycota; c__unidentified	0.011	0.027	-0.72
	Abundance of classes associated with decreased juice YAN			
Bunch no. per vine	C7 k__Fungi; p__Ascomycota; c__Eurotiomycetes	0.072	0.019	-0.75
	C28 k__Fungi; p__Chytridiomycota; c__Chytridiomycetes	1.54	0.031	-0.70
	Abundance of classes associated with decreased bunch number per vine			
Vine crown porosity	C27 k__Fungi; p__Blastocladiomycota; c__unidentified	0.072	0.016	+0.77
	Abundance of classes associated with increased crown porosity			
Yield	C5 k__Fungi; p__Ascomycota; c__Archaeorhizomycetes	0.17	0.057	-0.63
	Abundance of classes associated with decreased yield			

Langhorne Creek bacteria

Results show that bacterial communities in grapevine rhizosphere were predominately comprised of organisms belonging to the classes gamma-Proteobacteria (21.1%), alpha-Proteobacteria (14.7%), Actinobacteria (7.21%), Cytophagia (5.7%), beta-Proteobacteria (4.9%) and delta-Proteobacteria (4.9%) (Table 9).

As for Nuriootpa, significant differences in bacterial community components were observed at Langhorne Creek, depending on vineyard under-vine treatments. Increased abundances of Cytophaga and Anaerolineae in the rhizosphere were associated with wallaby grass. Kasbah cocksfoot was associated with increased Chloroflexi ‘S085’, Chloroflexi Anaerolineae, an

unknown class SJA-4 and Mollicutes. The control treatments had increased abundance of Chlorobi, Chloroflexi, Bacilli and Gemmatimonadete 'Gemm-2'.

Table 9a: Abundances of bacteria level 3 (Class) rhizosphere, Langhorne Creek, 2016-17

Bacteria	**Total abundance (%)**
C4 k__Unclassified; Other; Other	0.011
C5 k__Archaea; p__Crenarchaeota; c__Thaumarchaeota	1.09
C7 k__Archaea; p__Euryarchaeota; c__Halobacteria	0.047
C10 k__Archaea; p__Euryarchaeota; c__Thermoplasmata	0.183
C11 k__Archaea; p__[Parvarchaeota]; c__[Parvarchaea]	0.061
C12 k__Bacteria; Other; Other	0.164
C14 k__Bacteria; p__AD3; c__ABS-6	0.0056
C17 k__Bacteria; p__Acidobacteria; c__	0.0139
C18 k__Bacteria; p__Acidobacteria; c__AT-s54	0.0250
C19 k__Bacteria; p__Acidobacteria; c__Acidobacteria-5	0.089
C20 k__Bacteria; p__Acidobacteria; c__Acidobacteria-6	**2.48**
C21 k__Bacteria; p__Acidobacteria; c__Acidobacteriia	0.036
C22 k__Bacteria; p__Acidobacteria; c__BPC102	0.0111
C23 k__Bacteria; p__Acidobacteria; c__DA052	0.017
C24 k__Bacteria; p__Acidobacteria; c__EC1113	0.033
C26 k__Bacteria; p__Acidobacteria; c__PAUC37f	0.0139
C27 k__Bacteria; p__Acidobacteria; c__RB25	0.017
C28 k__Bacteria; p__Acidobacteria; c__S035	0.100
C29 k__Bacteria; p__Acidobacteria; c__Solibacteres	0.522
C30 k__Bacteria; p__Acidobacteria; c__Sva0725	0.311
C31 k__Bacteria; p__Acidobacteria; c__TM1	0.050
C32 k__Bacteria; p__Acidobacteria; c__[Chloracidobacteria	**1.65**
C33 k__Bacteria; p__Acidobacteria; c__iii1-8	**2.69**
C35 k__Bacteria; p__Actinobacteria; c__Actinobacteria	**1.63**
C36 k__Bacteria; p__Actinobacteria; c__Actinobacteria	**7.21**
C37 k__Bacteria; p__Actinobacteria; c__MB-A2-108	**4.17**
C38 k__Bacteria; p__Actinobacteria; c__Nitriliruptoria	0.019
C40 k__Bacteria; p__Actinobacteria; c__Rubrobacteria	0.244
C41 k__Bacteria; p__Actinobacteria; c__Thermoleophilia	**3.47**
C42 k__Bacteria; p__Armatimonadetes; c__0319-6E2	0.050
C45 k__Bacteria; p__Armatimonadetes; c__OPB50	0.0056
C47 k__Bacteria; p__Armatimonadetes; c__[Fimbriimonadia]	0.208
C49 k__Bacteria; p__BRC1; c__PRR-11	0.042
C50 k__Bacteria; p__Bacteroidetes; Other	0.031
C51 k__Bacteria; p__Bacteroidetes; c__At12OctB3	0.050
k__Bacteria; p__Bacteroidetes; c__BME43	
C53 k__Bacteria; p__Bacteroidetes; c__Bacteroidia	0.033
C54 k__Bacteria; p__Bacteroidetes; c__Cytophagia	**5.70**
C55 k__Bacteria; p__Bacteroidetes; c__Flavobacteriia	1.83
C57 k__Bacteria; p__Bacteroidetes; c__Sphingobacteriia	**2.30**
C58 k__Bacteria; p__Bacteroidetes; c__VC2_1_Bac22	
C59 k__Bacteria; p__Bacteroidetes; c__[Rhodothermi]	0.0167
C60 k__Bacteria; p__Bacteroidetes; c__[Rhodothermi]	3.63
C61 k__Bacteria; p__Chlamydiae; c__Chlamydiia	**1.97**
C62 k__Bacteria; p__Chlorobi; Other	0.022
C63 k__Bacteria; p__Chlorobi; c__	0.061
C64 k__Bacteria; p__Chlorobi; c__BSV26	0.0083
C66 k__Bacteria; p__Chlorobi; c__OPB56	0.053
C67 k__Bacteria; p__Chlorobi; c__SJA-28	0.025
C69 k__Bacteria; p__Chloroflexi; c__	0.0111
C70 k__Bacteria; p__Chloroflexi; c__Anaerolineae	**1.53**
C71 k__Bacteria; p__Chloroflexi; c__C0119	0.0167

Bacteria	**Total abundance (%)**
C72 k__Bacteria; p__Chloroflexi; c__Chloroflexi	0.231
C73 k__Bacteria; p__Chloroflexi; c__Ellin6529	0.928
C74 k__Bacteria; p__Chloroflexi; c__Gitt-GS-136	0.106
C75 k__Bacteria; p__Chloroflexi; c__Ktedonobacteria	0.0083
C76 k__Bacteria; p__Chloroflexi; c__P2-11E	0.0167
C77 k__Bacteria; p__Chloroflexi; c__S085	0.125
C78 k__Bacteria; p__Chloroflexi; c__SAR202	0.0139
C79 k__Bacteria; p__Chloroflexi; c__TK10	0.161
C80 k__Bacteria; p__Chloroflexi; c__TK17	0.111
C81 k__Bacteria; p__Chloroflexi; c__Thermomicrobia	0.292
C82 k__Bacteria; p__Cyanobacteria; Other	0.0083
C83 k__Bacteria; p__Cyanobacteria; c__	0.022
C84 k__Bacteria; p__Cyanobacteria; c__4C0d-2	0.039
C85 k__Bacteria; p__Cyanobacteria; c__Chloroplast	**1.09**
C86 k__Bacteria;p__Cyanobacteria;c__ML635J-21	0.031
C87 k__Bacteria; p__Cyanobacteria; c__Nostocophycideae	0.228
C88 k__Bacteria; p__Cyanobacteria; c__Oscillatoriophycideae	0.031
C89 k__Bacteria; p__Cyanobacteria; c__Synechococcophycideae	0.0056
C91 k__Bacteria; p__Elusimicrobia; c__Elusimicrobia	0.233
C93 k__Bacteria; p__FBP; c__	0.019
C94 k__Bacteria; p__FCPU426; c__	0.0083
C95 k__Bacteria; p__Fibrobacteres; c__Fibrobacteria	0.150
C98 k__Bacteria; p__Firmicutes; c__Bacilli	0.867
C99 k__Bacteria; p__Firmicutes; c__Clostridia	0.017
C100 k__Bacteria; p__GN02; c__3BR-5F	0.0056
C102 k__Bacteria; p__GN02; c__BD1-5	0.0083
C107 k__Bacteria; p__GN04; c__GN15	0.011
C110 k__Bacteria; p__Gemmatimonadetes; c__	0.128
C111 k__Bacteria; p__Gemmatimonadetes; c__Gemm-1	0.786
C112 k__Bacteria; p__Gemmatimonadetes; c__Gemm-2	0.253
C113 k__Bacteria; p__Gemmatimonadetes; c__Gemm-3	0.125
C114 k__Bacteria; p__Gemmatimonadetes; c__Gemm-5	0.308
C115 k__Bacteria; p__Gemmatimonadetes; c__Gemmatimonadetes	0.76
C117 k__Bacteria; p__MVP-21; c__	0.0056
C119 k__Bacteria; p__NKB19; c__TSBW08	0.0139
C120 k__Bacteria; p__Nitrospirae; c__Nitrospira	0.472
C121 k__Bacteria; p__OD1; Other	0.0056
C122 k__Bacteria; p__OD1; c__	0.022
C123 k__Bacteria; p__OD1; c__ABY1	0.044
C124 k__Bacteria; p__OD1; c__Mb-NB09	0.075
C125 k__Bacteria; p__OD1; c__SM2F11	0.031
C126 k__Bacteria; p__OD1; c__ZB2	0.097
C129 k__Bacteria; p__OP11; c__OP11-3	0.044
C130 k__Bacteria; p__OP11; c__WCHB1-64	0.0056
C131 k__Bacteria;p__OP3; c__PBS-25	0.028
C132 k__Bacteria; p__OP3; c__koll11	0.028
C134 k__Bacteria; p__Planctomycetes; Other	0.0167
C135 k__Bacteria; p__Planctomycetes; c__	0.0111
C136 k__Bacteria; p__Planctomycetes; c__028H05-P-BN-P5	0.0167
C137 k__Bacteria; p__Planctomycetes; c__BD7-11	0.039
C138 k__Bacteria; p__Planctomycetes; c__C6	0.089
C139 k__Bacteria; p__Planctomycetes; c__ODP123	0.0111
C140 k__Bacteria; p__Planctomycetes; c__OM190	0.319
C141 k__Bacteria; p__Planctomycetes; c__Phycisphaerae	0.608

Bacteria	**Total abundance (%)**
C143 k__Bacteria; p__Planctomycetes; c__Pla4	0.053
C144 k__Bacteria; p__Planctomycetes; c__Planctomycetia	3.25
C146 k__Bacteria; p__Planctomycetes; c__vadinHA49	0.033
C147 k__Bacteria; p__Proteobacteria; Other	0.150
C148 k__Bacteria; p__Proteobacteria; c__	0.108
C149 k__Bacteria; p__Proteobacteria; c__Alphaproteobacteria	**14.66**
C150 k__Bacteria; p__Proteobacteria; c__Betaproteobacteria	**4.94**
C151 k__Bacteria; p__Proteobacteria; c__Deltaproteobacteria	**4.89**
C152 k__Bacteria; p__Proteobacteria; c__Gammaproteobacteria	**21.1**
C153 k__Bacteria; p__Proteobacteria; c__TA18	0.056
C157 k__Bacteria; p__Spirochaetes; c__Spirochaetes	0.019
C158 k__Bacteria; p__Spirochaetes; c__[Leptospirae]	0.044
C160 k__Bacteria; p__TM6; c__SBRH58	0.0083
C161 k__Bacteria; p__TM6; c__SJA-4	0.178
C163 k__Bacteria; p__TM7; c__MJK10	0.022
C164 k__Bacteria; p__TM7; c__SC3	0.044
C167 k__Bacteria; p__Tenericutes; c__Mollicutes	0.092
C169 k__Bacteria; p__Verrucomicrobia; Other	0.0139
C171 k__Bacteria; p__Verrucomicrobia; c__Opitutae	0.978
C173 k__Bacteria; p__Verrucomicrobia; c__Verrucomicrobiae	0.72
C174 k__Bacteria; p__Verrucomicrobia; c__[Methylacidiphilae]	0.044
C175 k__Bacteria; p__Verrucomicrobia; c__[Pedosphaerae]	**1.47**
C176 k__Bacteria; p__Verrucomicrobia; c__[Spartobacteria]	**1.61**
C177 k__Bacteria; p__WPS-2; c__	0.0083
C179 k__Bacteria; p__WS2; c__SHA-109	0.0056
C180 k__Bacteria; p__WS3; c__PRR-12	0.206
C181 k__Bacteria; p__[Thermi]; c__Deinococci	0.0083

Table 9b: Langhorne Creek rhizosphere bacteria level 3 (Class) abundance (%)

Treatment	C54 Bacteria; p__Bacteroidetes; c__ Cytophagia	C63 Bacteria; p__ Chlorobi	C70 Bacteria; p__ Chloroflexi; c__ Anaerolineae	C76 Bacteria; p__Chloroflexi; c__ P2-11E	C77 Bacteria; p__Chloroflexi; c__ S085	C98 Bacteria; p__Firmicutes; c__ Bacilli	C112 Bacteria; p__ Gemmatimonadetes; c__ Gemm-2	C138 Bacteria; p__ Planctomycetes; C6	C151 Bacteria; p__ Proteobacteria; c__ Deltaproteobacteria	C161 Bacteria; p__ TM6; c__ SJA-4	C167 Bacteria; p__ Tenericutes; c__ Mollicutes
Kasbah cocksfoot	0.0498 ab	0.00050 ab	0.0218 a	0 b	0.00300 a	0.00875 ab	0.00125 b	0.00100 ab	0.558 ab	0.00325 a	0.00200 a
Wallaby grass	0.0735 a	0 b	0.0213 a	0 b	0.00025 b	0.00675 ab	0.00275 b	0.00175 a	0.0663 a	0.00125 b	0.00125 ab
Angel/Sultan Medic	0.0695 ab	0 b	0.0105 b	0 b	0.00075 ab	0.00475 b	0.00100 b	0.00025 b	0.0440 ab	0.00100 b	0 b
Control (herbicide)	0.0351 b	0.00194 a	0.0075 b	0.000667 a	0.00100 ab	0.01442 a	0.00511 a	0.00056 b	0.0297 b	0.00161 b	0.00042 ab
Mean	0.0570	0.00061	0.0153	0.000167	0.00125	0.00867	0.00253	0.00089	0.0489	0.00178	0.00092
P	0.031	0.022	0.002	0.012	0.036	0.026	0.002	0.018	0.021	0.003	0.017
l.s.d.	0.02616	0.001253	0.00652	0.0004076	0.001823	0.005865	0.001670	0.000859	0.02137	0.000980	0.001153
	P	P	P	F	F	P	P	P	P	P	P
	P	P	P	F	P	P	P	P	P	P	P

At Langhorne Creek, fungi increased soil Colwell P, soil Fe, soil HWC, soil moisture, soil total C, soil total N, juice Baumé, juice Brix, juice acidity and juice YAN.

Certain bacterial communities were also increased in the grapevine rhizosphere under different vineyard under-vine treatments. The effects of these bacteria on the soil nutrient cycle and suppression of grapevine fungal disease is an important area for future investigation.

The results reported here indicate that the under-vine amendments have had large effects on the microbiological community structure of vineyard soils and the grapevine rhizosphere. The changed microbial populations have further been associated with changes in the soil nutrients, juice parameters and vine growth.

Economics

Nordblom et al. (2018) simulated gross margins using two years of trial site yield data to show benefits of up to 19% or $890/ha in growing medics or medic and ryegrass under-vine, compared with the herbicide control (Figure 21). Achieving such benefits through other forms of vineyard management, through either cost savings or productivity gains, is very difficult, making these results a very significant outcome at this site.

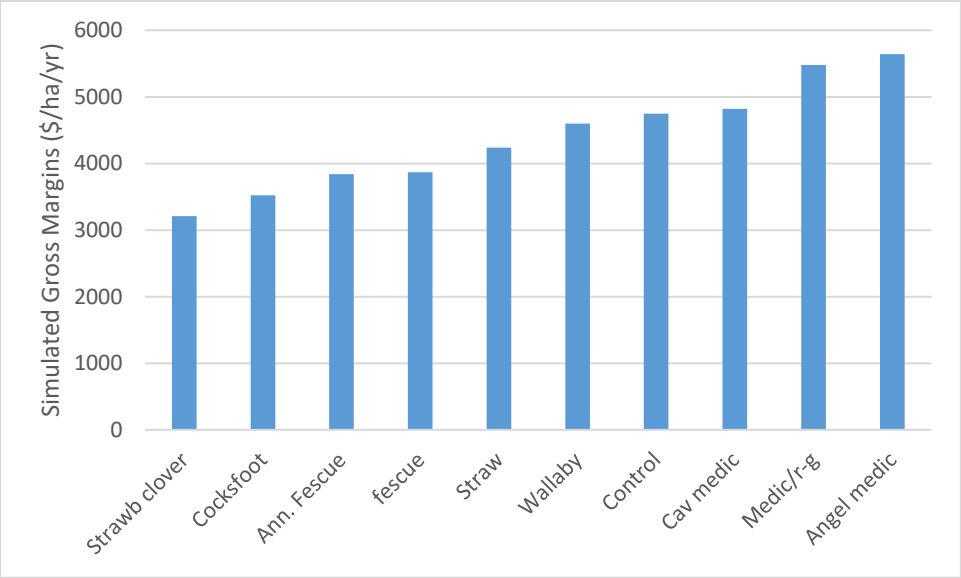


Figure 21: The effect of cover crop on simulated gross margins for Langhorne Creek (Nordblom et al., 2018)

Eden Valley

This site was sown in May 2015 and was chosen due to its cooler climate and higher rainfall than other sites in the project. Water is supplied by a dam and a bore, which struggled with supply in the dry 2015/16 season. The vineyard manager strives to attain very high quality but not at the expense of respectable yields. The under-vine cover crops are therefore under close scrutiny to ensure yield and quality are not compromised. The results to date however have encouraged him to next year plant under-vine cover crops in a Cabernet vineyard.

Seasonal conditions

As the coolest and wettest of the cover cropping sites, Eden Valley provided some additional challenges but the potential for some very useful outcomes for growers in that region, where the higher rainfall and cooler conditions might be advantageous for the cover crops. The 2015/16 season was very challenging due to a lack of water and a very hot finish. Severe berry shrivel in the Shiraz resulted in very depressed harvest yields. A wet 2016/17 season by comparison provided some excellent yields and notable treatment differences. The changes in seasonal weather are shown in Figure 22.

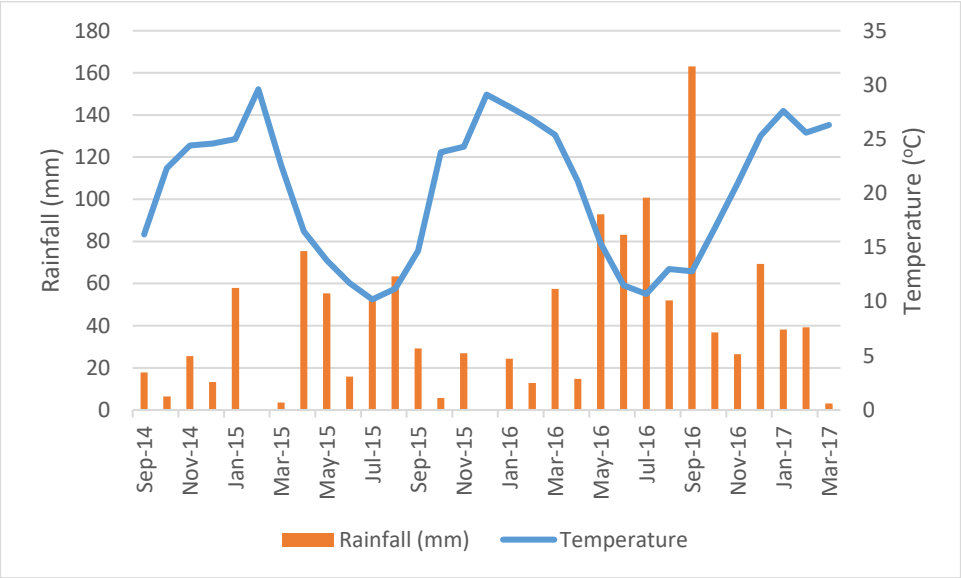


Figure 22: Rainfall and temperature experienced at Eden Valley

Botanical composition of under-vine cover crops

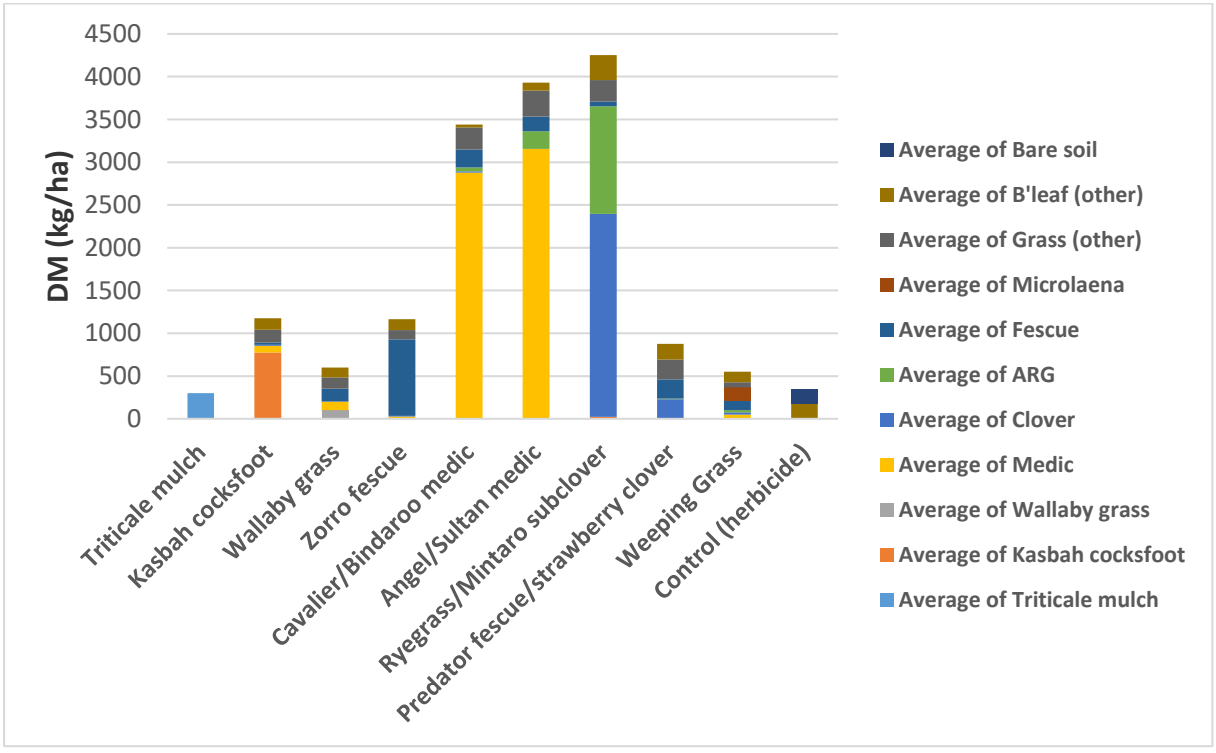
As the site was sown in autumn 2015, biomass production of the perennials (Kasbah cocksfoot, wallaby grass, fescue/strawberry clover and weeping grass) in the first year was limited by time taken to establish and a very dry spring period. One of the main purposes of cover crops is to suppress weed growth and the consequent need for herbicide application. All treatments except the straw mulch had some weeds, including the herbicide control. To maintain the integrity of the trial, once the Botanal assessment was complete, weeds when possible were removed by spot application of glyphosate. While this may not be possible from a commercial grower perspective, they may instead be able to apply selective herbicides over the whole site, or mow later in the season to suppress seed set of the weed.

The annual medics and sub-clover performed very well in this first year, producing large amounts of biomass and setting copious quantities of seed to regenerate from in the following year (Figure 23, Plate 3). The intention with all the species chosen was that they would be low maintenance once established, and behave as established perennials or regenerate from seed reserves.

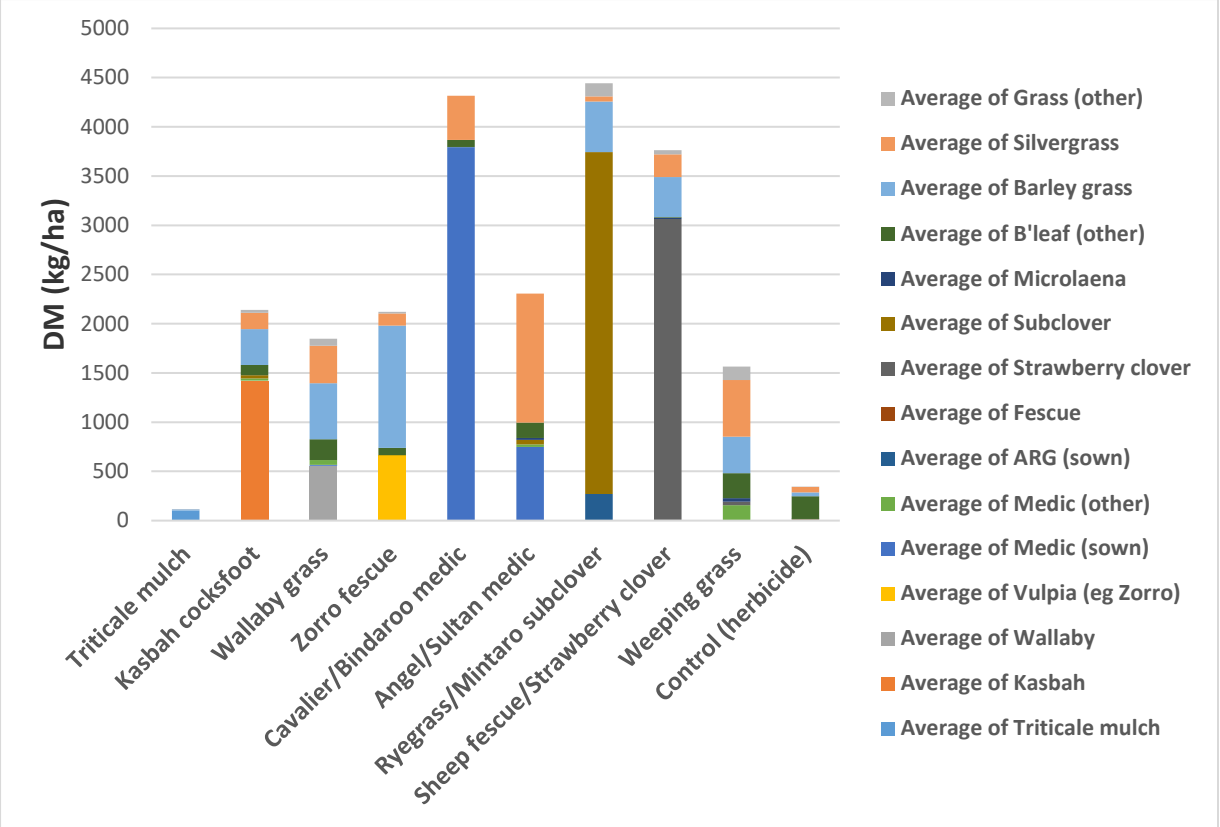
Secondly, the cover crops were intended to improve soil quality. This would include improved soil nutrient status, soil physical characteristics and soil biological status. From the nutrient perspective, the legumes perform a critical role. For each tonne of dry matter (biomass) produced, they also supply roughly 20 kg of symbiotically fixed nitrogen. In the first year, the clover and medics produced between 2.5 and 3 t/ha of biomass, equating to 50 to 60 kg/ha of nitrogen in the under-vine zone (Figure 23a). This figure must be divided by

the area of under-vine cover crop (assuming the mid-row does not contain legumes) so with about a third of the vineyard being the under-vine zone, about 20 kg/ha of N is produced by the legumes. With approximately 1.5 kg N/t of grapes being removed from the vineyard, the nitrogen fixed will readily account for the needs of a 10 t/ha crop, assuming losses through leaching and volatilisation are not great.

The maintenance of legume dominant cover crops is not without challenges and grasses, both sown and endemic, invade when nitrogen levels rise. Essentially, they are nature's mechanism for ensuring soil N levels do not get too high. It is often noticed in arable pastures where after a couple of years of legume dominance, the legumes self-regulate by failing to grow well, and grasses and nitrophilous weeds then dominate the pasture (Medd et al., 1987). A similar effect is apparent in the under-vine zone at several sites, which is likely to be advantageous on several fronts. High soil N, and thereby berry and must N, should be prevented from raising must pH, aroma and colour (Proffitt and Campbell-Clause, 2012) with the utilisation of N by the grass cover crops. When soil N subsides, the legumes should then re-colonise the site using the dormant seed bank established in prior years. Barley grass is the dominant soil cover at this site, and it invaded several treatments in 2016. The succession of species (from legume to grasses) has probably been hastened at this site by its inherent soil fertility which has also masked the benefits of the legumes witnessed at other less fertile sites.



(a)



(b)

Figure 23: Botanical composition in under-vine cover crops at Eden Valley for spring (a) 2015 and (b) 2016.



(a)



(b)



(c)



(d)

Plate 3: Under-vine cover crops at Eden Valley, 25 November 2016: (a) cocksfoot, (b) straw on left hand side and medic on the right, (c) silvergrass and (d) wallaby grass (19 January 2017)

Yields

Due to the stressed and shrivelled status of fruit harvested in 2015/16 season, yield data have not been provided in this report as it was not a true representation of the treatment impacts.

The harvest yields from the 2016/17 vintage, shown in Figure 24, display considerable yield suppression attributable to the native wallaby grass (*Rytidosperma* spp.) and weeping grass (*Microlaena* spp.). Both are C3 grasses, which in seasons with low summer rain and no irrigation would normally lead them to become dormant over the summer period. However, the wet summer and applied irrigation have encouraged summer growth, which was to the detriment of vine yields. Of interest also is the yield achieved on the cocksfoot treatment, which is also a summer dormant perennial. Despite remaining green throughout the growing season, it did not have the same detrimental impact on vine yield as the other perennial grasses. Overall, the highest yield came from annual medic, then other annuals, the straw mulch and the herbicide control were all similar in yield. The ability of straw mulch to reduce moisture loss and insulate the soil appeared to be a disadvantage in the wet 2016/17 season, which kept the soil cool for longer and thus delayed budburst. The soil at this site is not degraded like the Nuriootpa site, so the herbicide control has a higher relative yield. Importantly, the annual cover crop species have not reduced yields compared to the herbicide control or the straw mulch, so financially, as shown by Nordblom et al. (2018), the medic annual cover crop has the best monetary returns.

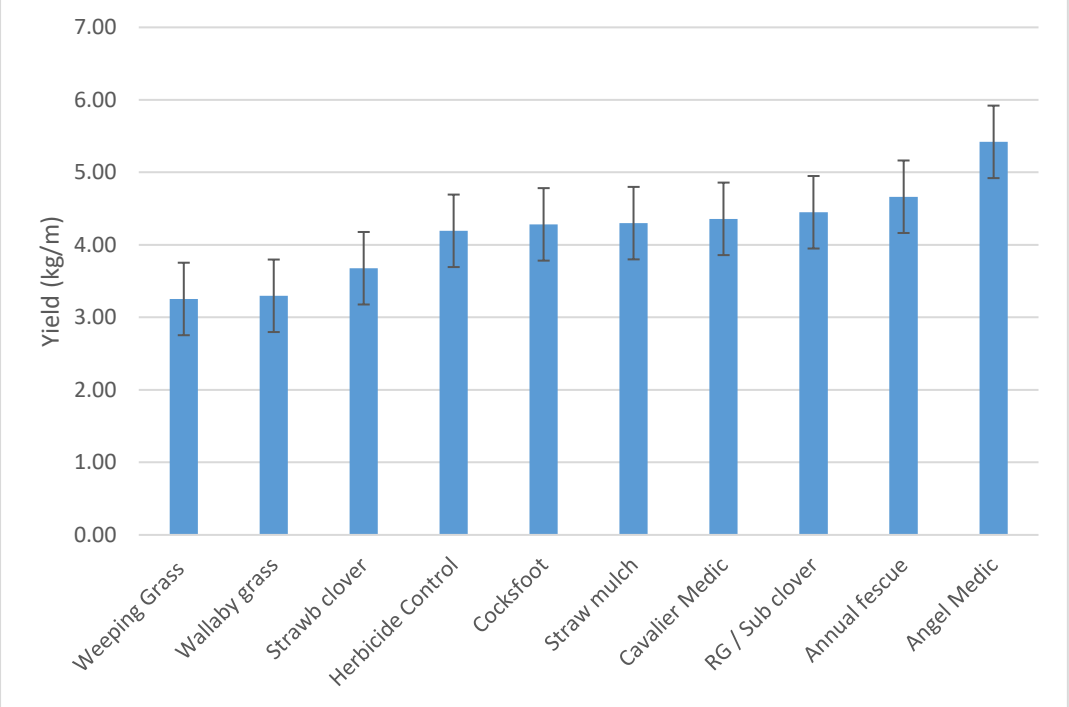


Figure 24: Eden Valley harvest yields, 2016-17

At the Eden Valley site there was a positive correlation between soil carbon and grape yield (r^2=0.72). This is important, as one of the project objectives was to improve soil quality with a consequent yield improvement. Given the intimate link between soil carbon and nitrogen, it

is not surprising to see that bunch weights are also correlated, while petiole N and NO_3 are correlated with berry weight. It is of interest to note an apparent link between petiole sodium concentration and bunch numbers, but a negative impact on cane weights. It is counter-intuitive to think that higher concentrations of sodium may be beneficial, but the mean concentration (0.05%) was below the recommended 0.1–0.3%, so it is possible that the positive correlation was not just chance. The strong negative correlation of sodium on cane weights is also possible, with Walker (2010) reporting reductions in cane numbers (which will affect weights) due to salinity. It is possible that as soil moisture availability diminished towards veraison (when vegetative growth would have ceased), that a greater concentration of salt may have been taken up by the vines. As the under-vine cover crops are changing the soil moisture profile, as evidenced from the Nuriootpa site, it is important that the potential for increasing salinity levels is monitored to ensure the long-term sustainability of the practice is not compromised.

Vine responses to cover crops

As shown in Table 7, there were no significant differences in leaf area or vine canopy prior to harvest in 2017. Bunch numbers, determined in the inflorescence primordia during the dry spring of 2016, were different, with the clover/ryegrass treatment the highest, and straw with the lowest numbers. Soil temperature (data not shown) was within one degree across all treatments, so is unlikely to have had an impact. Higher LAIe and cane weights in 2015/16 would suggest a larger canopy in the straw treatments, leading to greater light interception which may have reduced the inflorescence primordia for the 2016/17 season.

Berry weights were lowest on the perennial cover crop treatments, and highest for the straw, herbicide and ryegrass/clover treatments, but the correlation with yield was poor.

Cane weights were higher on the straw treatments, suggesting greater access to soil moisture through the growing season. These translated into lower Y:P ratios for the straw than all other treatments, with Angel medic having the highest. All Y:P ratios except ryegrass/clover treatment were within the acceptable range of from 5-10 as recommended by Smart and Robinson (1991). According to Edwards (pers. com. 2017), the critical factor for vine balance, especially in the cool climate regions, is having enough leaf to ripen the fruit. As noted with the Brix, there were no significant differences, suggesting the ryegrass/clover treatment, though slightly outside the recommended Y:P ratio range, has still ripened fruit as well as other treatments.

Table 7: Key vine parameters as they were affected by under-vine cover crop treatments

	LAIe	Crown Porosity	Bunches (#/vine)	Bunch wt. (g)	Yield (kg/m)	50 Berry wt (g)	Total acid	Brix (Hh)	Petiole K%	Petiole N %	Petiole NO3	Petiole Na %	YAN	Soil Total N (%)	Soil Total C (%)	Canes (#/m)	Canes (kg/m)	Y:P (kg/kg canes)
Straw mulch	2.68	0.15	54.85a	126.6	4.3b	71.5c	5.76	22.3	4.57b	1.89c	2123c	0.04a	487	0.214	1.97	32.6	0.77c	5.54a
Cocksfoot	2.28	0.18	72.21cd	100.5	4.28ab	57.4ab	5.87	21.9	3.98ab	1.47ab	493a	0.05bc	459	0.183	1.73	31.2	0.52a	7.03ab
Wallaby grass	2.03	0.23	74.68cd	76.9	3.3ab	57.5ab	5.81	22.6	4.19ab	1.44a	349a	0.05bc	487	0.189	1.53	28.3	0.53a	6.71ab
Annual fescue	2.47	0.17	66.07ab	116.2	4.67bc	59.1ab	6.26	22.2	4.3b	1.44a	346a	0.05bc	480	0.182	1.72	31.1	0.53a	8.33bc
Cavalier medic	2.47	0.15	80.22cd	92.6	4.36bc	55.9	6.07	21.5	3.84ab	1.55ab	406a	0.06c	390	0.180	1.78	30.6	0.54a	9.44cd
Angel medic	2.38	0.18	81.73cd	110.8	5.42c	65.8abc	6.79	21.5	3.55a	1.6ab	637a	0.06c	398	0.181	1.81	29.0	0.53a	10.53d
R/G Clover mix	2.39	0.18	84.12d	86.4	4.45bc	67.0c	6.97	21.4	3.6a	1.67abc	533a	0.052bc	421	0.168	1.72	30.4	0.65b	7.89bc
Strawberry clover	2.33	0.19	69.35bc	90.1	3.68ab	60.2ab	5.95	22.0	4.14ab	1.727bc	657a	0.05bc	444	0.174	1.61	28.9	0.54a	7.04ab
Weeping Grass	2.08	0.21	69.86bc	89.0	3.25a	63.9abc	6.63	22.1	4.29b	1.49ab	510a	0.056bc	468	0.158	1.50	30.0	0.55ab	6.43ab
Herbicide control	2.48	0.17	73.42cd	95.6	4.19ab	67.9c	5.98	21.7	4.33b	1.56ab	1258b	0.05bc	414	0.172	1.74	32.7	0.56ab	6.67ab
Site Mean	2.36	0.18	72.7	98.5	4.19	62.6	6.207	21.9	4.1	1.6	731.0	0.05	445	0.180	1.71	30.5	0.571	7.56
F pr.	0.46	0.10	0.014	0.056	0.041	0.03	0.20	0.51	0.04	<0.01	0.06	0.01	0.43	0.28	0.13	0.15	0.004	0.011
CV%	16	18	13	19	18	10.3	13	3.4	2.6	11.3	6.5	2.2	17	26	30	8.9	14	23
LSD (P=0.05)	NS	NS	13.82	NS	1.08	9.41	NS	NS	0.620	534.000	0.280	0.009	NS	NS	NS	NS	0.10337	2.023

Soil properties

Table 8 shows the total soil carbon, nitrogen and phosphorus resulting from treatment implementation over two years. There were no significant differences in any of the properties measured, reflecting the short period of implementation for this site, and the soil quality being better than at other sites. Indeed, as noted by Sanderman et al. (2010), long term trials are critical to achieving accurate data on soil organic matter. Trials that are terminated after short periods, which may be up to 14 years, will potentially provide flawed data on the true impact of management change to soil carbon levels.

Phosphorus levels at the Eden Valley site are extremely high, especially on the straw treatment. There was also a strong correlation (r^2=0.9) for soil carbon and soil phosphorus, suggesting the soil P may be driving this high soil C which is evident under the straw mulch. Kirkby et al. (2011) reported on the ratios of C:N:P:S that are required for the formation of soil humus (SOM) - they are C 10,000: N 833: P 200: S 143. They also calculated the cost of NPS fertiliser to generate one tonne of stable humus at $248 (in 2011 dollars). In a subsequent paper, Kirkby et al. (2014) performed an incubation experiment with wheat straw (we used triticale straw as mulch) and found a net loss of fine fraction carbon in the soil, while straw with added nutrients gained fine fraction carbon. Potentially the inherent fertility at this site is enabling the sequestration of additional soil carbon from straw, which was not possible at the other sites. In the Eden Valley vineyard case, phosphorus is in plentiful supply. Sulfur is supplied mostly by rainfall, but was not measured at this site. It is suggested however, that despite the straw having a high C:N ratio, there was possibly enough N, P and S in the soil to convert some of the carbon contained in the straw into soil organic carbon. This is in stark contrast to the Nuriootpa site, where no gain in carbon was measured on the straw treatment, probably due to the poor availability of other nutrients that Kirkby et al. (2011) identified as being essential to improving soil organic carbon.

Table 8: Soil analysis for Eden Valley, showing no significant differences between under-vine treatments

	Total Carbon (%)	**Total N (%)**	**Colwell P (mg/kg)**
Straw mulch	2.0	0.22	148.8
Cocksfoot	1.8	0.19	90.8
Wallaby grass	1.3	0.16	62.8
Annual fescue	1.3	0.15	52.0
Cavalier medic	1.7	0.19	81.8
Angel medic	1.4	0.14	60.5
R/G Clover mix	1.7	0.17	77.8
Strawberry clover	1.7	0.18	87.2
Weeping Grass	1.7	0.19	100.5
Herbicide control	1.6	0.16	78.2
Mean	**1.6**	**0.17**	**84.0**

Economics

For the 2017 season, Nordblom et al. (2018) found substantial differences in gross margins between the control and medic/ryegrass under-vine treatments (Figure 25). Caution must be used here as it is based on only one year's yield data. However, the combination of significantly higher yield on the Angel medic treatment, coupled with lower operational costs suggest improved financial returns if those outcomes are sustained.

The substantial reductions in gross margins attributed to the wallaby and *Microlaena* native grasses is a result of their own success. Both species grew very well at this site over the summer period and have consequently reduced the vine yields considerably. The saying 'It's hard to be green when you are in the red' is very appropriate here if the yield data are supported in future years.

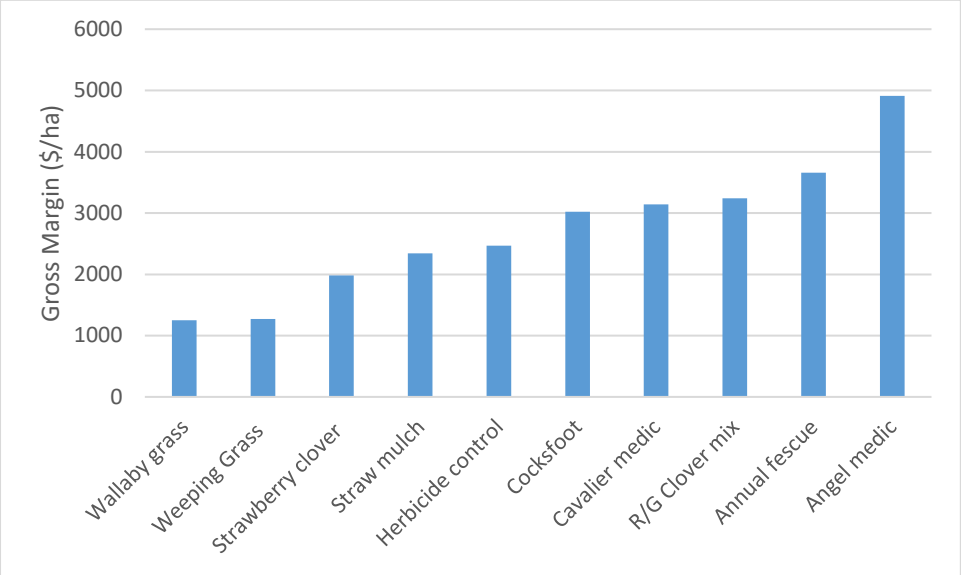


Figure 25: Under-vine cover crop treatment impacts on simulated gross margins for Eden Valley, 2017 (Nordblom et al., 2018)

Waikerie

The warm-hot inland regions produce the vast majority of winegrapes in Australia, so they were very deserving of a trial site investigating the potential for increasing vineyard profitability while reducing the need for herbicides in the under-vine zone. There are several issues with under-vine management in the region that require research input, with herbicide resistance, new weeds (e.g. Rhodes grass) and water infiltration being key concerns. Five herbicide applications to the under-vine zone per year are generally required to maintain a weed free environment, and these have associated application, chemical and environmental costs. The project has made progress on addressing these issues, but unfortunately budgetary constraints will prevent the investigation of further possibilities.

Seasonal conditions

Low rainfall coupled with soils of poor water holding capacity and higher temperatures than areas closer to the coast mean the vines in the inland region are highly dependent on irrigation water (Figure 26). Approximately 6 ML/ha is generally applied by drippers, and it is important that this water is used efficiently. Past work with under-vine mulching in the Riverland showed little impact on yield from mulch/compost application (Penfold, 2004), unlike vineyards in the higher rainfall zones. Nutrient and water saving benefits were overshadowed by the high water application rates and fertigation of nutrients. Using cover crops to overcome issues with problematical weeds without reducing yields in this environment also presented a considerable challenge.

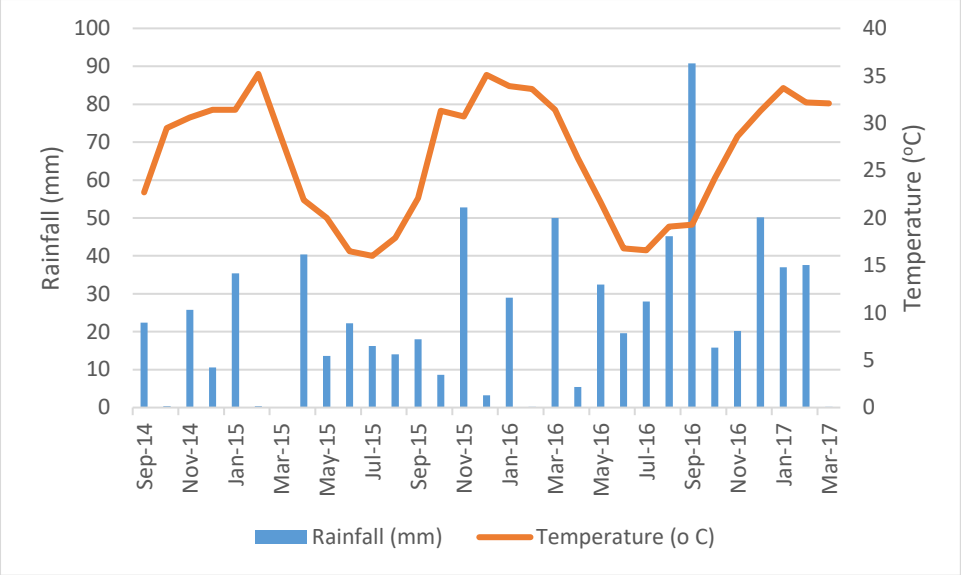


Figure 26: Monthly mean maximum temperature and rainfall data for Waikerie experienced during the project period.

Botanical composition of under-vine cover crops

While the lighter textured soil of the Waikerie site is well suited to the lower rainfall experienced in the inland regions, there are still plenty of challenges associated with establishing and maintaining desirable soil cover. No cover crops are sown in the mid-rows as establishment and productivity is very unreliable, so management concentrates on the resident species and using minimal intervention. The under-vine area is kept bare using herbicides, with particular emphasis on summer weeds such as fleabane, fat hen, milk thistle and prickly lettuce, which can become aggressive invaders if left unchecked.

Establishment of the cover crops can be difficult if adverse seasonal conditions are encountered. The seeds are small, requiring shallow sowing depths (about 1 cm), but this soil also dries quickly if warm conditions are experienced following seeding. Fortunately, conditions favoured germination but the dry spring in 2014 reduced seed set and required reseeding of most treatments in 2015.

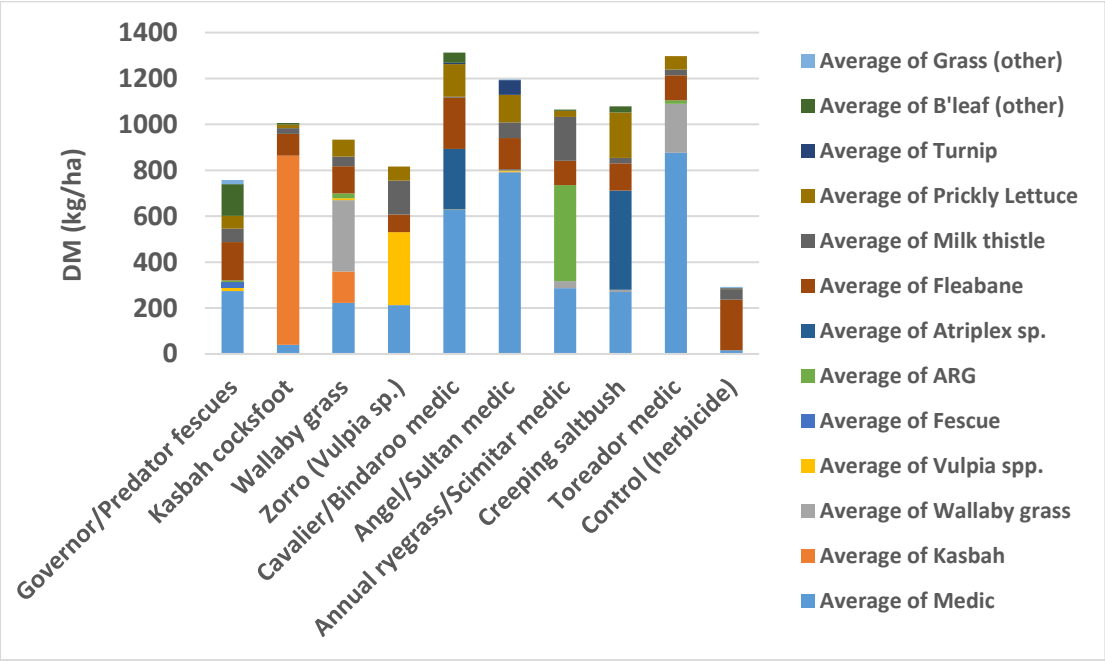
Figure 27 shows the dramatic improvement in dry matter production in 2016 compared with 2015, which was attributed to the older perennial plants and the wetter winter and spring. In 2015, limited rainfall restricted growth, but fleabane, milk thistle and prickly lettuce were able to germinate with the help of irrigation. While the sown cover crops were dominant, in a commercial vineyard the weed invasion would have necessitated some control as all the problematic weed species have the capacity to grow into the vine canopy.

The best performing under-vine cover crop species at this site were the Kasbah cocksfoot and Toreador medic. Both established well and maintained their stand (cocksfoot) or regenerated each year from their seed reserves (medic). In some cases, the plants grew well on the southern (shaded) side of the vine, but could not cope with the radiant heat on the northern side (wallaby grass, sheep and creeping red fescue) of the vine row. The short growing season of the medics was well suited to this environment, but their biomass production was not sufficient to generate a mulch capable of suppressing weed establishment. They also provided a desirable environment and no competition for summer weed growth, necessitating herbicide control in spring once the medics had set seed.

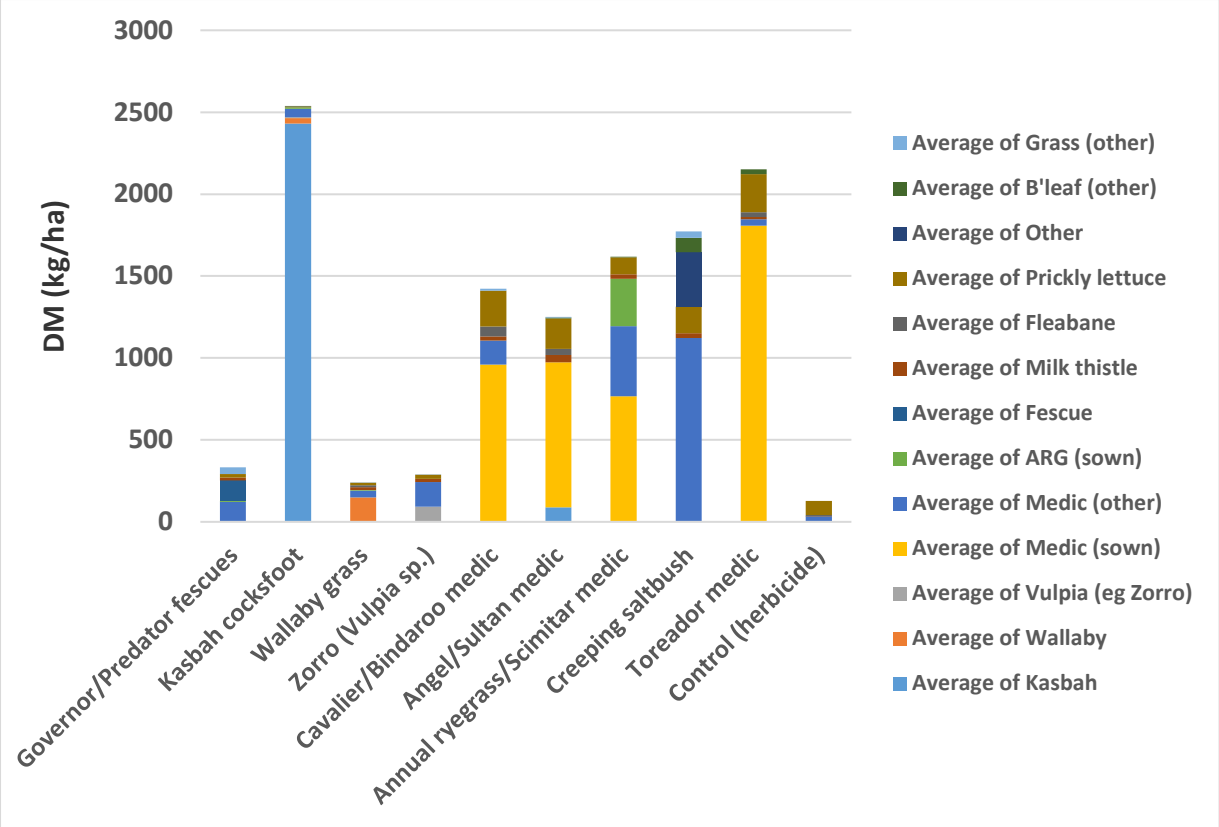
Creeping saltbush (*Atriplex semibacatta*) is a prostrate xerophyte well suited to arid inland conditions. However, from past trial work and this project, it has been shown to be quite selective in where it will grow well, and the under-vine zone at this site was not a preferred site. Previous work when growing it in the mid-row has shown very effective competition and smothering of

weeds including caltrop, and it has been grown successfully under-vine at other sites (Moulds pers. com.). That treatment effectively became a minimal herbicide control.

Regarding the cover crops capacity for constraining weed growth, the cocksfoot performed outstandingly well throughout both years (see Figure 27, Plate 4). Despite the expectation it would have summer dormancy, the cocksfoot responded to irrigation and remained active throughout the year. This provided a hostile environment for growth of summer weeds, but also led to competition with the vine and significant yield loss in the 2016/17 season. To determine if the yield suppression could be reduced by mowing (or simulated sheep grazing), the cocksfoot was maintained at a height of about 15 cm during 2017, with yield to again be measured in 2018. An alternative practice would be to invoke dormancy by spray-topping the cocksfoot in spring, only burning off the above ground growth, and having it regenerate the following autumn. This option may be enough to sustain yields, depending on whether weeds invade the stand over summer and use water instead of the cocksfoot.



(a)



(b)

Figure 27: Botanical composition of under-vine cover crop treatments at Waikerie for Spring (a) 2015 and (b) 2016


(a)



(b)



(c)

Plate 4: Kasbah cocksfoot (a) and Toreador medic (b) growing under-vine 24 October 2016, and (c) weed growth under-vine in the Toreador medic treatment, Waikerie, 1 December 2016

Vine yield

Figure 28 only displays eight of the 10 treatments originally sown, as the Zorro fescue and the prostrate saltbush did not perform at this site.

The 2016/17 season yielded 60% more than 2015/16, probably influenced by the wetter and milder conditions in the latter year. The 2017 season also generated a significant yield difference between the Kasbah cocksfoot and two highest yielding treatments – the control and a mix of hard and creeping fescues. The latter are low statured hardy perennial grasses which have survived some very harsh conditions without reducing vine yield. In this situation they have not spread (from their own seed) to fill the gap between the two sown rows, so it would appear that a different seeding system would be required to prevent weed growth throughout the under-vine zone. It is however very promising to see this potential candidate as a non-competitive cover crop option.

The cocksfoot has been competitive however. It has grown really well considering the tough environment, and worked very well at excluding weeds, but the yield suppression (19% in 2016, 17% in 2017) is too great for it to be a viable option. However, to see if this yield loss can be reduced, for the 2017/18 season the cocksfoot has been mown to reduce transpiration (which will also equate to grazing for the winter period).

As shown in the Botanal chart (Figure 28) the medics, and particularly Toreador, performed well, and importantly, did not cause a yield reduction. This finding needs further consideration, as it means there is no reason why growers should not grow them under-vine, but they will still have to apply herbicides in late spring (after medic seed set) and possibly summer to control the summer weeds. This should still allow soil improvement to steadily occur with minimal cost to the grower, and may lead to addressing infiltration concerns expressed earlier.

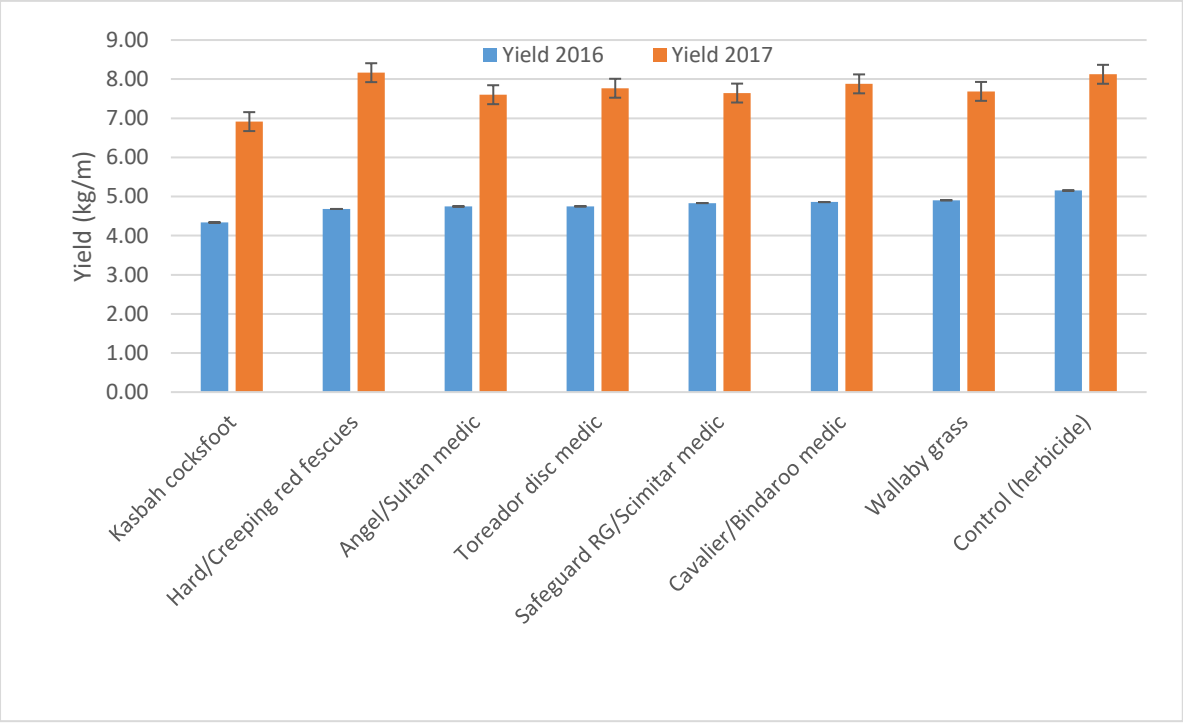


Figure 28: Vine yield for years 2016 and 2017, Waikerie

Petiole nutrition

Petiole nutrient analysis conducted on the three treatments representing stark contrasts in cover crops – control, Toreador medic and cocksfoot, showed no treatment differences on any of the suite of elements tested. In the relatively short timeframe of the trial, the medic has not influenced

nitrogen availability, but this is also likely overshadowed by fertigation supplying readily available nutrients.

Fruit quality

As shown in Table 9, there was little difference in fruit quality in 2017, and none in 2016. Titratable acidity was lower on the medic treatments than the cocksfoot, but in commercial terms this may still be insignificant.

Table 9: Fruit quality changed little between treatments, Waikerie, 2017.

	50 Berry wt (g)	Total acid	VA	TA	Malic	TSS	Brix	YAN
Kasbah cocksfoot	55.1	5.41	0.052	10.62c	0.84	20.02	21.78	230
Hard/Creeping red fescues	54.7	5.37	0.094	10.19bc	0.74	19.18	21.06	176
Angel/Sultan medic	56.7	5.15	0.036	9.89bc	0.78	19.19	21.02	221
Toreador disc medic	57.7	4.57	0.042	8.63a	0.84	18.93	19.80	216
Safeguard RG/Scimitar medic	56.2	4.90	0.059	9.49b	0.72	19.47	21.34	245
Cavalier/Bindaroo medic	55.1	5.20	0.058	9.929bc	0.74	19.53	21.29	226
Wallaby grass	55.9	5.47	0.080	10.1bc	0.93	19.08	21.06	210
Control (herbicide)	54.9	5.07	0.054	9.89bc	0.59	19.60	21.37	238
Site Mean	**55.8**	**5.1**	**0.059**	**9.9**	**0.8**	**19.4**	**21.1**	**220.3**
F pr.	**0.26**	**0.11**	**0.39**	**0.015**	**0.29**	**0.16**	**0.13**	**0.07**
CV%	**3.5**	**7.5**	**53.0**	**6.1**	**24.0**	**2.4**	**3.6**	**14.3**
LSD (P=0.05)	**NS**	**NS**	**NS**	**0.836**	**NS**	**NS**	**NS**	**NS**

Vine responses to under-vine cover crops

The Waikerie site is minimally pruned, which negates the capacity to take pruning weights or leaf area index measurements, due to the amount of dead wood residing in the canopy. Yield for most Riverland growers is the critical factor in profitability (they have little control over price) and that is their focus in vineyard management. As such, the use of Kasbah cocksfoot would not be recommended despite the capacity for weed suppression. There was no positive response to the cover crops either, with the nitrogen being produced by the medics probably inadequate to address the demands of high yielding crops in that environment.

Soil properties

There were no significant changes to any of the soil chemical properties measured on the three treatments that were analysed viz. control, cocksfoot and Toreador medic. The mean soil total carbon (0.52%), total nitrogen (0.06%) and Colwell phosphorus (16.2 ppm) are all considered low but not uncommon for this soil type in the dry inland region. Despite a legume-based cover crop which had no residue removed, there was still no impact on soil C or N. There are very good reasons for this, as highlighted by Sanderman et al. (2010). Carbon is lost about 20 times faster from sandy compared to clay soils. Additionally, irrigation, especially over summer, provides the ideal environment for microbial decomposition of the carbon, exacerbating the issue further. Lower quantities of biomass production also inhibit carbon accumulation. It is however likely that the perennial grasses, and especially the cocksfoot, will be storing carbon deeper in the soil profile (Sanderman et al., 2010). The soil in this project was only sampled in the 0-10 cm zone, as this is where most of the carbon, roots and microbial activity occur. Deeper soil sampling in the 10-30 cm zone may show benefits in soil carbon accumulation from the perennial grasses.

While quantifiable soil improvement, via organic carbon levels, are not evident at this site, it does not mean the growing of plants under-vine is not beneficial to the soil. Providing microbial diversity via living plants and improving general soil health is a worthy strategy, so long as there are no productivity or financial losses associated with the practice.

Economics

As shown in the attached paper (Nordblom et al., 2018), the yield suppression attributed to Kasbah cocksfoot was quite effective at reducing gross margins at this site. Of the treatments that grew well, the cocksfoot reduced gross margins by 23% compared to the control, while the medic had an insignificant $200/ha reduction in gross margin. That may or may not be replicated in other instances – for example would it be the same with more aggressive rootstocks such as Ramsay, or will the suggested changes to management of cocksfoot (grazing/mowing and/or spray topping in spring) prevent the yield loss while negating the need for under-vine herbicides. These are important questions which do require answers, as growing an under-vine cover crop in this region which prevented or reduced the need for herbicides would be very attractive for both conventional and organically managed vineyards.

OUTCOMES and CONCLUSIONS

This project was funded under the Vineyard Profitability program of Wine Australia. As noted by the project title, it was proposed in the funding application that by growing suitable cover crop species under the vine row it should be possible to reduce costs of weed control, as this zone was responsible for the most management inputs to the floor of the vineyard. It was also proposed that by improving soil quality through stopping herbicide use and encouraging the growth of desired plant species, improved crop yields and potentially fruit quality would result.

Both objectives have been met. Weed growth has been significantly reduced at all sites through suppression by species that competed strongly with weeds or suppressed their germination. At Waikerie, weed growth was prevented by Kasbah cocksfoot, but the associated reduction in yield was too great for this strategy to be recommended. The dry inland environment, requiring regular applications of water to achieve desired production levels, also provides the ideal environment for growth of some very aggressive weed species (fat hen, prickly lettuce and fleabane) which were not suppressed by the cover crop mulch produced by the winter/spring active annuals. For the Riverland region, the project has created more questions than answers. However, the continued use of herbicides and maintenance of a clean under-vine zone is not sustainable due to the onset of herbicide resistance and potential reduction in access to herbicides in the longer term. This project has shown the benefits and costs associated with growing perennial grasses under-vine in the warm, dry inland environment. Given the potential risks associated with not progressing with this work, the outcomes of this project should be utilised to develop further projects addressing management of the under-vine zone in this region.

In contrast to the Riverland site, in the Barossa the herbicide control treatment generated a lower gross margin than straw mulch, Kasbah cocksfoot and a medic/ryegrass mix, with the latter treatment generating long-run after-cost increases in gross margins of $1,600 to $1,700/ha annually above the $5,000/ha of the herbicide control treatment (Table 3 in Nordblom et al., 2018). While this increase will not occur on all soil types across the Barossa, it is an outstanding result, providing an option for growers to consider where their soil is likely to be similarly responsive.

At the Eden Valley and Langhorne Creek sites, the medic and medic/ryegrass treatments also maintained or improved yields, with the control gross margins only third best (Eden Valley) or second best (Langhorne Creek). Given the considerable research effort dedicated to improving vineyard productivity and fruit quality, it would appear this project has shown that over a short

time frame, the novel practice of under-vine cover cropping with suitable species can achieve the objective of improving productivity and potentially fruit and wine quality at minimal cost or risk.

The assessment of soil biology has been compromised by the delay in accessing the Next Generation Sequencing data. As seen in this report, a huge amount of information is generated, and that will be replicated when the Eden Valley and Waikerie sites are also analysed. Potentially, the annual clover treatment is associated with plant pathogens that may be the cause of suppressed yields. While numerous correlations have been shown, further investigation of causal relationships needs to be undertaken before any conclusions can be drawn from this large body of work.

It is often difficult to measure the impact of research on the industry that supports it. In this case, interest in the research has been considerable, as shown by the number of seminar presentations requested by grower groups (see Appendix 1). Some growers who have hosted trials or seen the trial sites are also looking to adopt the practice, with one large company vineyard to sow 25 ha in the Barossa this year. Wine Tasmania is implementing its own trials with support from the PI, and Mornington Peninsula growers are also considering their own sites. It is important for growers to be provided with the information to implement the use of under-vine cover crops with the correct species for their vineyard. Our trials to date suggest this will be either clovers or medics mixed with annual ryegrass. Simply allowing non-selected plants to grow under-vine is however likely to lead to disappointment with the change in practice.

The system developed in this project was not successful universally. Initially, under-vine cover cropping was attempted on an organic vineyard in addition to those operated conventionally and cited in this report. It was found to be very difficult to establish and successfully grow a cover crop in the under-vine zone, which contained a large seed bank of weeds that had to be reduced prior to seeding. With limited weed control options available, and despite several tillage passes, it was very difficult for the sown species to dominate the plant population. Further work in organic vineyards should instead target the mid-row where the use of false seedbeds could more readily be implemented for weed control. Cover crops of the desired species could then be sown, and following seed maturity but before seed drop, they could be mown and thrown under the vine. This method of delivering large quantities of seed to that zone is potentially a cost-effective means of manipulating the plant population in the under-vine zone in favour of those that are likely to provide a productivity benefit.

In addition to the successful implementation of the field trials, other performance targets have also been met. The Cover Crop Finder decision support tool (covercropfinder.com.au), originally developed for supporting growers in their selection of mid-row cover crops, has now been updated to include under-vine cover cropping as an optional selection. Clovers, medics and ryegrass have been recommended as preferred options based on the work to date. The PI's contact details have also been provided so growers can access additional information. A fact sheet reflecting outcomes to date from the project has also been written.

In summary, the multi-site trials have shown how grapegrowers in most regions can grow suitable annual plant species under-vine to create their own mulch, suppress the growth of many weeds, improve soil quality, vine productivity and financial returns for very little input cost or risk to their operation.

RECOMMENDATIONS

To realise the potential for grapegrowers to improve productivity and financial returns from under-vine cover cropping, it is recommended the following direction for research and extension is adopted:

- Continue research trials. As we are dealing with changing some fundamental characteristics of the soil, such as soil organic carbon, and its influence on perennial and annual plants, a lot remains to be gained in understanding plant succession, soil improvement and their long-term impact on financial returns from ongoing investigation.

- Interrogate the NGS data for all sites to determine causal relationships between cover crop treatment, soil biology, soil quality and vine productivity. This then needs to be translated into layman's terms for the benefit of the wider community.
- To foster the uptake of research outcomes, strategically located demonstration sites need to be established and maintained for a minimum of three years. Field days associated with these sites will enhance their value to the local growers.
- The development of a blog site for the housing of under-vine cover cropping information. This will enable local and overseas work to be readily accessed from the one site by interested parties.
- Building on results from this project, further work in the hot dry environments is required to help overcome water infiltration issues, slow down the onset of herbicide resistance, and build soil quality.
- Cover crops have difficulty establishing at some sites that have been managed with herbicides for long periods. It is suspected that the soil biology is populated with an abundance of plant pathogenic species that restrict plant growth, especially in the first year of establishment. Studies to determine if this is the case, and if so, provide ways to rapidly restore a diverse soil biology should be undertaken.
- Sheep grazing in vineyards post-harvest and through winter is now a common practice. Vineyards can provide useful feed and protection to stock which are now valuable commodities. Growing cover crops across the vineyard floor to benefit the vine and the sheep, and their management should be further investigated, particularly for the inland environments where taller trellises and suitable sheep breeds could enable extended grazing periods, thereby reducing management costs.
- Pot trials investigating allelopathy on young vines induced by various cover crops were initiated at Wagga Wagga, producing some very interesting results. Potentially, pasture species sown by growers are allelopathic to vines, particularly while young, thereby supressing vine growth.
- Investigate the potential for other native species to be used for under-vine cover cropping, with an emphasis on enhancing floral and invertebrate biodiversity.
- Management packages need to be developed and made available to agribusiness, so they can promote the under-vine cover cropping concept in return for seed sales.

Appendix 1: Communications

2014

April: Waite: *Vineyard Cover cropping*. Student lecture.

July:
Morphettville Racecourse: Ground Sprayers Conference, *Non-chemical Weed Control Options*. Seminar presentation

August:
Waite Institute: *Organic Viticulture* Presentation to Viticulture students

September:
Gemtree Cellar Door: *The Gemtree Trial – Organic, Biodynamic and Conventional Viticultural Systems Compared.* A summary of results from the six year Wine Australia-funded trial, presented to members of the McLaren Vale Grape Wine and Tourism organisation prior to a formal tasting of wines produced from the trial.

October:
Eden Hall Vineyard, Eden Valley: Field day held for the Rowland Flat Agricultural Bureau
Nuriootpa Research Centre: Creating Resilient Landscapes on your Property. *Viticultural, environmental and economic benefits of native grass cover crops, and the development of a low-input under-vine management system.* Field trip organised by the Barossa Valley Grape and Wine Association.

Pecador Vineyard, Langhorne Creek: *Native Grasses and Vineyard Floor Management* Field Day and Seminar.

2015

Bleasdale Vineyards, Langhorne Creek: Seminar and field day including cover cropping used at Pecador vineyards.

Padthaway Bowling Club: *Vineyard Cover Cropping* Seminar organised by the Padthaway Grape Growers Association.

Yarra Valley Community Centre: *Vineyard Floor Management and Soil Health.* Seminar.

2016

Nepenthe Cellar Door, Balhannah: *Vineyard Floor Management for Enhanced Biodiversity.* Seminar.

Mornington Peninsula, Gippsland, Yarra Valley: *The development of a low-input under-vine floor management system which improves profitability without compromising yield or quality*. AWRI Roadshow Seminar series to three regions in Victoria.

Nuriootpa Football Clubrooms: *Is your vineyard Bare* OR *Are you reaping the benefits of mulch and compost, and a healthy mid-row and under-vine?* Under-vine cover cropping presentation to the Barossa grower breakfast & information session. Barossa Grape and Wine Assoc.

Yalumba Signature Room: *The development of a low-input under-vine floor management system which improves profitability without compromising yield or quality*. Background information on

the trial presented prior to a tasting by 26 winemakers and viticulturists. Organised by Barossa Vine Improvement Society.

Berri Hotel: *Vineyard Floor Management and Soil Health.* Seminar and Field Day organised by Riverland Wine.

Coonawarra Hall: *Vineyard Floor Management and Soil Health.* Seminar and Field Day organised by Coonawarra Vignerons Assn.

Southwest University, Chongqing, China: *Improving vineyard floor management with less inputs.* Seminar presented to staff and post graduate students of the College of Resource and Environmental Sciences.

Wirra Wirra Wines: *Cover cropping and weed management* **and** *The Gemtree Trial – Organic, Biodynamic and Conventional Viticultural Systems Compared.* Seminar organised by the McLaren Vale Grape and Wine Tourism Association.

AWRI Webinar: *Vineyard Cover Cropping*
Vineyard floor management and soil health **and** *The relative sustainability of Organic, Biodynamic and Conventional Viticulture.* Seminar organised by the Orange Region Vignerons Assn.

2017

Launceston and Hobart: *The development of a low-input under-vine floor management system which improves profitability without compromising yield or quality.* AWRI Roadshow Seminar Series.

The Winehouse, Langhorne Creek: *The development of a low-input under-vine floor management system which improves profitability without compromising yield or quality*. AWRI Roadshow Seminar Series.

Ararat, Milawa, Geelong, Mornington Peninsula, Yarra Valley: *Mulching and Cover Crop Management.* Victorian Regional Focus Workshops, AWRI.

Penfolds Magill Estate: *Developing a low-input under-vine management system to improve profitability without compromising yield or quality.* Presentation to the Treasury Wine Estates Technical Group.

Carrick Hill: *Under-vine cover cropping has yield and quality benefits.* Crush 2017, Waite Institute (**Please note:** Following presentation of this paper, an award for the project having the greatest industry impact amongst the Crush presentations was presented to the PI on behalf of the project team).

Presentations by Dr Melanie Weckert

Invited to present paper at Australian Native Seeds workshop, Melbourne on effects on grapevines of Wallaby grass. 'Wallaby grass, a potentially beneficial ground cover for viticulture: soil microbial diversity'. 15-17 November 2016. Melanie Whitelaw-Weckert, Chris Penfold.

Invited to present at conference, UNE: 'Restore, Regenerate, Revegetate'. 'Ryegrass and fescue allelopathy may inhibit plant growth and seed germination', 5 February 2017.
Melanie Whitelaw-Weckert, Jennifer Bannister, Robert Lamont, Jim Pratley, Mark Norton and Chris Penfold.

Presentations by Jake Howie

Developing a low-input under-vine management system to improve profitability without compromising yield or quality. Presentations made to the McLaren Vale and Barossa growers within the AWRI Roadshow Seminar Series, 2017.

Cover crops can reduce the cost of under-vine weed control. Presented at the Weed Management Society of South Australia 6th SA Weeds Conference. Charles Hawker Conference Centre, Urrbrae, May 2018

Papers accepted for presentation

Penfold, C., Weckert, M., Howie, J., Nordblom, T., Norton, M. *Developing a low-input under-vine management system to improve profitability without compromising yield or quality*, GiESCO, Argentina, November 2017.

Nordblom, T., Penfold, C., Weckert, M. and Norton, M. (2017). *Straw and living mulches compared with herbicide for under-vine weed control in a Public-Private Benefit Framework*, ABARES Conference, Brisbane, 2017.

Nordblom, T., Penfold, C., Weckert, M., Norton, M., Howie, J. and Hutchings, T. (2018). *Economic and financial risks in under-vine management alternatives to herbicide in four South Australian wine-grape districts, 2016-2017*, ABARES Conference, Adelaide, 2018.

Articles

Australian & New Zealand Grapegrower & Winemaker, September 2016. First report: some ryegrass and fescue cover-crops may damage grapevines. Melanie Whitelaw-Weckert, Jim Pratley, Jenny Bannister, Mark Norton, Chris Penfold.

Workshops organised by the PI

Australian Wine Industry Technical Conference, 24 July 2016. Adelaide. *Organic Viticulture*. Four speakers over 3 hours, 25 attendees.

Native Grasses – Enhancing Establishment Forum. 20-21 October 2016. Technology Park, Mawson Lakes. Organised in conjunction with the Salisbury City Council and Native Grass Resource Group. 80 attendees.

Resources developed from the project

The decision support tool covercropfinder.com has been updated to include under-vine cover cropping within the applications for cover crops, and a contact address for the PI should people require more detailed information.
A fact sheet has also been produced and will be provided to WA for inclusion on their website.

Further communication

With the extension of the project, the PI will continue to present workshops and seminars, with two already booked in for 2018 (Hobart in May and Margaret River in July). An outcome from attendance at the GiESCO conference in 2017 was making contact with numerous other researchers working in similar fields around the world. To maintain those contacts and enhance the adoption of cover cropping practices, a blog site will be developed enabling input from those involved in similar work. If requested, a workshop on cover cropping at the AWITC 2019 would also be appropriate.

It is also suggested that a short video highlighting the work be made in the spring and summer, to show the state of the cover crops and the vines at these two periods. This could be embedded within the blog site suggested above. It is also suggested that another AWRI Webinar be produced to focus on the outcomes of the under-vine project to date. An industry article is still to be produced on the project, which should also generate grower interest in the work.

Appendix 2: Intellectual property

While a considerable amount of learning has occurred throughout this project, there is no intellectual property to be gained from it.

Appendix 3: References

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Appendix 4: Staff

Chris Penfold	Project Supervisor and Chief Investigator
Dr. Melanie Weckert	Chief Investigator / microbiologist
Jake Howie	Pasture agronomist and biometrician
Ass. Prof. Tom Nordblom	Economist
Dr. Mark Norton	Pasture scientist

Casual staff who also provided greatly appreciated support during field sampling and laboratory analysis included:

Harry Penfold
Alastair Howie
Rhianna Penfold
Jenny Bannister
Rob Lamont
Ian Maddock
Ben Slattery

Appendix 5: Relevant Material

Please see attached three peer reviewed conference papers.

Penfold, C., Weckert, M., Howie, J., Nordblom, T., Norton, M. *Developing a low-input under-vine management system to improve profitability without compromising yield or quality*, GiESCO, Argentina, November 2017.

Nordblom, T., Penfold, C., Weckert, M. and Norton, M. (2017). *Straw and living mulches compared with herbicide for under-vine weed control in a Public-Private Benefit Framework*, ABARES Conference, Brisbane, 2017.

Nordblom, T., Penfold, C., Weckert, M., Norton, M., Howie, J. and Hutchings, T. (2018). *Economic and financial risks in under-vine management alternatives to herbicide in four South Australian wine-grape districts, 2016-2017*, ABARES Conference, Adelaide, 2018.

Appendix 6: Budget reconciliation

Provided online to Wine Australia via Clarity.

DEVELOPING A LOW-INPUT UNDER-VINE MANAGEMENT SYSTEM TO IMPROVE PROFITABILITY WITHOUT COMPROMISING YIELD OR QUALITY

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Abstract

The under-vine region of the vineyard floor contains the greatest concentration of vine roots, so management of this zone directly impacts vine yield, quality and profitability. The removal of weeds involves regular use of herbicides or cultivation, neither of which is recognised as best practice soil management. Resultant herbicide resistant weeds, poor soil quality and restricted access to soil moisture may adversely affect vine growth. Under-vine cover crops are being compared with herbicide and straw mulch controls for their impact on yield, fruit, wine and soil quality, suppression of weeds and economic response at five sites in South Australia. The cover crop species consist of annual and perennial native or exotic grasses and legumes.

Despite under-vine cover crop biomass of up to 8 t/ha following a very dry spring, at some sites treatments showed improved grape yields in 2016 compared with the herbicide and straw mulch controls. Different cover crop species had distinctive effects on grapevine root colonisation by beneficial arbuscular mycorrhizal fungal (AMF). Next Generation Sequencing of the vineyard soil showed that some cover crops were more strongly associated with Glomeromycota, the fungal division containing the AMF. Fruit quality was not compromised by the cover crops, and in a sensory analysis of Shiraz wine from the Barossa site, the herbicide control was rated lowest of seven treatments. Perennial cover crops which remained active over summer helped to suppress summer weeds but also reduced yields at most sites. In this paper we report on results from one selected site.

Keywords: cover crops, weeds, herbicides, soil quality, wine quality.

Introduction

The under-vine strip of about 1 metre width represents approximately 30% of the vineyard floor area, but receives a much greater proportion of management inputs, mostly as herbicide applications or cultivation. This is a costly use of resources with potentially deleterious environmental impacts, especially to the zone of soil in which the greatest concentration of vine roots are found. Management of this zone is therefore likely to impact vine yield, fruit quality and vineyard profitability. Cover cropping is now common practice in the vineyard mid-rows with its recognised benefits to the soil, plants and general ecosystem (Pardini et al, 2002, Ingels et al. (1998). By growing desirable plant species in the under-vine zone, it is intended to enhance those ecological benefits without reducing vine yield or fruit quality.

The vineyard conundrum is that the zone of soil with the greatest level of root activity and potential influence on quality is not being treated in line with best soil management practice because undesirable plants (weeds) are growing in that space and need to be removed. There are several alternatives to herbicides available to grape-growers, such as mulching, mowing, cultivation and sheep grazing, but all have their limitations. A proposed option is to instead grow desirable plant species in the under-vine zone, which provide benefit to the vine while suppressing the growth of weed species. Ideally the desirable species will be self-regenerating annuals or summer dormant perennials which grow in autumn to smother weeds, provide root matter to improve soil structure, then die or go dormant either before extracting valuable moisture or later where excess vigour is an issue.

Soil organic matter (SOM) is the key to improving soil health, which can either be imported as compost or mulch, or grown in-situ. Other researchers have investigated using cover crops to improve the mid-row soil health. Sanderson (1998) noted a 75% increase in SOM over 4 years when vigorous medics were allowed to complete their life cycle. Fourie (2007), found that medic cover crops grown over a ten year period, increased SOM by over 20% compared with the herbicide control, and at greater than 1.5% SOM meant nitrogen additions were unnecessary in South African conditions.

Bell and Henschke (2005) discuss the implications of providing adequate nitrogen to ensure there is sufficient canopy for fruit ripening and yeast available nitrogen (YAN) levels to support a complete fermentation. In

the proposed study, legumes are potentially important components of the ground cover, which could in reasonable rainfall environments provide most of the N required by the vine.

In this paper we report the impact of sown cover crops grown under-vine on numerous important parameters for determining their fit within a sustainable viticultural system.

Materials and Methods

The trial was established in a block of 13 year old own-rooted shiraz in 2014 at the South Australian Research and Development Institute's Nuriootpa Research Centre in the Barossa Valley ($34^0 28^{'} 24$" S; $139^0 00^0 24^{'}$E). The duplex soil consists of an A horizon of sandy loam over a B horizon of sodic medium textured clay with high soil strength and the potential for inhibiting vine root growth. Ten treatments (Table 1) were replicated 4 times in a randomised complete block design, with each plot consisting of three panels, each with three vines. The vine spacing was 2.25 metres, giving a plot length of 20.25 metres. Row spacing was 3.5 metres. Following leaf fall in 2014, herbicide (glyphosate 540 g.a.i./L @ 2.0 L/ha and oxyfluorfen, 240 g.a.i./L @ 75 mL/ha) was applied to provide weed control. Plots were sown using a Taege® vineyard disc seeder, with a single row sown each side of the vines at a depth of 10 mm within 20 cms of the vine trunk, and chains behind the disc to cover the seed. No fertiliser was applied, but the legumes were inoculated with the appropriate rhizobium strain. Red legged earth mite, lucerne flea and sitona weevil were controlled with chlorpyrifos @ 350 mL/ha. The herbicide controls were maintained as bare earth with herbicide applications as required and straw mulch (triticale) was applied at 55 t/ha to the one metre wide under-vine zone. All plant species were allowed to fully express their phenology with no intervention used to manage or terminate growth. Seasonal conditions restricted cover crop growth and seed set in the first year, requiring some treatments to be re-sown in the second year. Cover crop productivity was high in both the second and third years.

Cover crop composition and dry weight was estimated 4 times per year using the Botanal (Tothill, et al. 1978) methodology. Vine vegetative production was determined from pruning weights, while vine canopy balance was estimated using the leaf area index generated by the VitiCanopy phone App (De Bei et al 2015). Petioles were sampled at 80% flowering for tissue analysis and vines were mechanically harvested and weights determined from load cells on a trailer which followed the harvester. Hand harvested fruit was used for winemaking, which followed the red winemaking protocols established by the Australian Wine Research Institute, using 10 L demijohns for the secondary fermentation. Wine sensory evaluation was conducted by a 26 member panel of Barossa Valley winemakers, using a 20 point scoring system.

Results and Discussion

Rainfall over the three growing seasons differed considerably (Figure 1). The rainfall in the 2014/15 and 2015/16 spring/summer periods were both below average and in 2016, with warmer soil temperatures, led to an early harvest. The 2016/17 spring/summer was comparatively wet, providing very contrasting seasons to test the impact of cover cropping on vine yield and fruit quality.

The establishment, performance and dry matter production of the cover crops varied considerably between species and over the two years post-establishment (data not shown). Although Kasbah cocksfoot was planted as a summer dormant species, the dry spring of 2015 necessitated early initiation of vineyard irrigation, which maintained its active growth and prevented it from entering true dormancy. Wallaby grass also remained green, though with much lower biomass produced. Strawberry clover remained green under the drippers and was the dominant species in 2015/16 while the fescue became more prevalent in 2016/17. The medics, annual clovers, *Vulpia* spp. and annual ryegrass set seed then senesced, leaving a dry mulch on the soil surface over the summer periods.

Petiole analysis from samples taken in December 2016 showed higher nitrogen levels in the herbicide control and straw mulch treatments. By harvest, a trend to higher YAN's in the must from legume treatments was apparent. From a winemaking perspective, adequate nitrogen availability in the must is preferred to additions in the winery, though excess nitrogen may lead to undesirable consequences such as rapid ferments and protein haze (Bell and Henschke, 2005). It is expected however that legume biomass production could potentially be manipulated to meet the winery requirements for YAN in fruit by mowing or grazing the forage.

While the cane number was lower on the straw mulch and strawberry clover treatments in 2016, there were no differences in cane weights, suggesting compensatory growth from those treatments.

Effective leaf area index (LAIe) and canopy porosity were used to determine canopy vigour prior to harvest. In the dry spring and summer of 2015/16, canopy vigour was greater with straw mulch and the herbicide control. The much wetter spring and summer of 2016/17 provided very different results, with the annual treatments (medic, medic and ryegrass, annual fescue) having the higher LAIe and lower crown porosity.

As shown in table 2, there were yield benefits compared to the herbicide control from some cover crop treatments in both years. In the dry 2015/16 season, the mulch treatment, driven by higher bunch numbers, was the highest yielding, and the annual medic and grasses were similar to the herbicide control. Perennial species of grass and legumes provided excess competition, compromising yields considerably. The wetter 2017 season showed the medic treatments to perform as well as the mulch treatment, while the perennials had similar yields to the herbicide control. In two years with very different amounts of rainfall the medic and ryegrass treatments performed equal to or better than the herbicide control. Soil carbon (0-10 cm) was also highest on the medic/ryegrass and perennial fescue/clover treatments. With only 3 years of data it is only possible to speculate that yield improvements occurred because the medics and ryegrass were feeding the soil microbial biomass, which in turn improved soil structure and root access to soil moisture. This hypothesis is however supported by gypsum block soil moisture tension data (not shown) which displayed less soil moisture at 100 cm in the medic/ryegrass treatment than the control over the spring period, but more at harvest, despite the high yield. The use of ryegrass to improve soil aggregate stability, reduce bulk density and improve available water is advocated by Tisdall and Oades (1979), who found ryegrass was more effective than white clover in stabilizing soil because it supported a larger population of Arbuscular Mycorrhizal Fungi (AMF) hyphae. Cockroft (2012) recognised soil coalescence and the resultant impediment to root growth as a major limitation to productivity in irrigated horticulture, and used dense plantings of ryegrass to improve soil structure.

Also of interest are two poor performing treatments, the annual *Vulpia* (2017) and the Mintaro sub-clover / Prima gland clover blend (2016), which is possibly a result of allelopathic interactions from the respective cover crops. Weckert (pers. com) found the Zorro fescue reduced young vine growth (and AMF colonisation) which may also translate to mature vines. Wang (et al, 2005) found coumarins on the leaf surface and in the leaf of *Trifolium glanduliferum* (cv. Prima) were the primary deterrent mechanism for red-legged earth mite which are a significant pest of pastures. Alexieva et al (1995) noted the plant growth regulating effect of coumarins on stem and root growth of wheat and cucumber while Razavi (2011) also recognised their fungitoxic nature, which may also impact on AMF populations. It is therefore possible this species of clover, which was expected to be desirable as a vineyard cover crop, has reduced grape yields through an allelopathic interaction with the vine.

Wine made from fruit harvested in 2016 was presented to a tasting panel nine months later. Their assessment showed a preference for wine made from the Kasbah cocksfoot treatment while the herbicide treatment was the least preferred. Belda et al. (2017) reviewed the current literature concerning the influence of the soil and its associated microbiota on wine characteristics and terroir. They noted how Next Generation Sequencing technology has enabled researchers to ascertain links between soil and root microbiomes and those in the grapes, and ultimately in the fermentation tanks. Potentially the cheapest and easiest way to alter the soil microbiology and influence wine flavour is by changing management practices of the under-vine zone, including the use of a range of cover crops. Further research will aim to determine the influence of cover crops on wine quality, and whether the association is via the soil microbiome or due to other edaphic factors such as changes to the soil's structure and impact on soil water relations.

A gross margins analysis compared the herbicide and straw mulch controls with the ryegrass/medic and cocksfoot treatments (Nordblom et al 2017). Not taking wine quality differences into account, the latter treatment had significantly lower gross margins due to the lower fruit yields, but there was no difference between the other treatments. Due to the limited yield and wine quality data set, this analysis has not attempted to determine impacts of potential improvements in soil or wine quality on financial returns. As more data is attained over coming years a broader focus will be possible in determining the real benefits (or costs) of under-vine cover cropping.

Conclusion

The continued removal of vegetation from the zone of greatest root activity in a vineyard will have negative impacts on soil quality. Growing under-vine cover crops using desired plant species which have low management demands but beneficial impacts on soil quality has the potential to also improve wine quality through edaphic or microbial means, which should lead to improved vineyard ecological and financial sustainability. It is expected the continuation of this research will provide a greater understanding of the changes in soil and wine characteristics resulting from implementing under-vine cover cropping systems.

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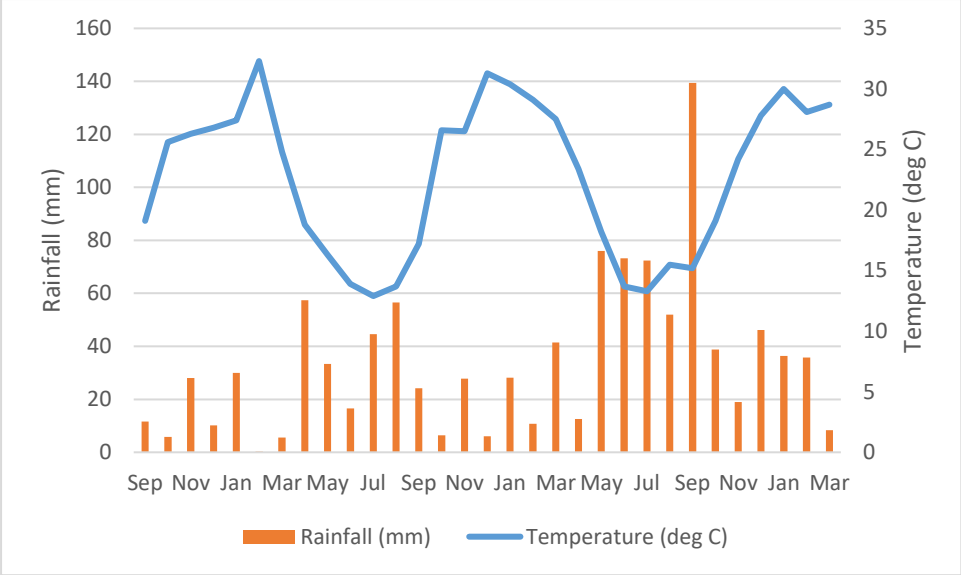


Figure 1: Monthly rainfall and average monthly maximum temperature over three growing seasons from September 2014 until March 2017, Nuriootpa, South Australia.

Table 1: List of treatments, plant species and under-vine sowing rates, Nuriootpa, South Australia 2014.

Common name (cultivar)	**Scientific name**	**Seeding Rate (kg/ha)**	**Plant type**
Cocksfoot (cv. Kasbah)	*Dactylis glomerata*	8	Summer dormant perennial grass
Rats tail fescue (cv. Zorro)	*Vulpia myuros*	10	Annual self-regenerating grass
Wallaby grass	*Rytidosperma geniculata*	10	Native perennial grass
Strand medic (cv. Angel); Barrel medic (cv. Sultan)	*Medicago littoralis* *Medicago truncatula*	20 20	Annual self-regenerating legumes
Spineless burr medic (cv. Scimitar); Annual ryegrass (cv. Safeguard)	*Medicago polymorpha* *Lolium rigidum*	20 30	Annual self-regenerating pasture legume and grass
Strawberry clover Sheep fescue	*Trifolium fragiferum* *Festuca ovina*	20 3	Perennial legume and grass
Gland clover (cv. Prima) Sub clover (cv. Mintaro)	*Trifolium glanduliferum* *Trifolium subterraneum ssp. brachycalycinum*	7 20	Annual self-regenerating pasture legumes
Regenerated weeds	*Medicago spp., Lolium rigidum, Trifolium spp.*		
Straw mulch (Triticale)	× *Triticosecale*		
Herbicide control			

Table 2: Treatments and selected measurement parameters, Nuriootpa, 2016-17

Treatment	Canes 2016 (#/m)	Canes 2016 (kg/m)	ELAI 2017	Crown Porosity 2017	Yield 2016 (kg/m)	Yield 2017 (kg/m)	Petiole N 2017 (%)	YAN	Soil Total C (%)
Triticale mulch	17.4	0.68	1.85	0.249	3.41	4.09	0.87	207	1.00
Kasbah cocksfoot	24.02	0.63	1.68	0.254	2.72	3.33	0.80	186	1.01
Wallaby grass	21.64	0.71	2.09	0.219	2.52	3.33	0.82	232	1.09
Zorro fescue	19.25	0.69	2.47	0.178	3.01	2.94	0.78	211	1.06
Regenerated weeds	19.92	0.82	2.32	0.193	3.04	3.28	0.83	218	1.14
Angel/Sultan medic	19.72	0.60	2.76	0.151	3.06	4.12	0.78	246	1.03
Safeguard RG/Scimitar medic	21.4	0.63	2.34	0.186	3.19	3.93	0.83	225	1.19
Sheep fescue/Strawberry clover	17.32	0.54	2.45	0.173	2.74	3.68	0.81	233	1.23
Mintaro sub-clover/Prima gland	18.41	0.59	1.89	0.24	2.46	3.47	0.84	213	1.10
Control (herbicide)	19.74	0.73	2.08	0.218	3.09	3.06	0.92	219	1.00
F pr.	0.03	0.40	0.004	0.01	0.04	0.05	0.02	0.29	0.02
Average LSD (P = 0.05)	3.8	NS	0.49	0.06	0.58	0.78	0.07	NS	0.14



Economic and financial risks in under-vine management alternatives to herbicide in four South Australian wine-grape districts, 2016 & 2017

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Economic and financial risks in under-vine management alternatives to herbicide in four South Australian wine-grape districts, 2016 & 2017

Abstract

We calculate financial risk profiles for representative vineyards of 50-ha in four wine grape regions of South Australia using straw or living mulches as alternatives to herbicides for under-vine management. Calculations are based on replicated experiments in a commercial vineyard in each district with the most widely grown vine variety of each; the grape yields were measured in 2016 and 2017. Published district grape prices and yields for the years 2006 through 2017 form the basis for novel stochastic analysis. The herbicide (Control) treatment in Barossa Shiraz (BS) and Riverland Merlot (RM) showed greater median Gross Revenues (prices x yields) than the other two districts: Eden Valley Shiraz and Langhorne Creek Cab-Sav. After subtraction of operating costs, and assuming alternative treatments produce grapes of equal quality and price as the Control in a district, the alternatives gave median Gross Margins ($/ha) greater than the Control in BS but lower than the Control in RM. Gross Margin results were mixed in the other two districts. The Gross Margin results above are magnified in financial Risk Profiles based on variations in Gross Margins times 50 ha across multiple ten-year periods after subtracting taxes, drawings, recurrent capital costs and interest on accumulating debt, for decadal cash margins. The Risk Profile of a treatment in a district is its cumulative distribution of decadal cash margins ($M). We show that choice of under-vine treatment can significantly affect a vineyard's financial viability.

Key words Farm financial risk, Risk profile, Decadal cash margin, Simulation, Under-vine treatments, Wine-grape production, South Australia

1. INTRODUCTION

The present study is a major up-date and supplement to a previous paper presented at AARES 2017 (Nordblom *et al*., 2017), which considered only a single year's harvest (2016) and only two wine-grape districts (Barossa and Langhorne Creek). The present study considers two years of harvest data (adding 2017) across four wine-grape districts (now including Eden Valley and Riverland districts). We make more direct use of district price and yield records published in the 12 most recent annual "***South Australian Winegrape Crush***

Survey" reports (Wine Australia, 2006 through 2017). From these reports it was possible to base a stochastic analysis of jointly correlated district by district yield and price variations to support simulations of baseline frequency distributions of Control treatment gross revenues.

Section 2 of this paper defines the basis for our stochastic analysis of district **Gross Revenue** distributions for the Control (herbicide) under-vine treatment. This allows consideration of simulated gross margins both as jointly-distributed random variates and as cumulative distribution functions. These are the distributions taken as the basis for simulating the other treatment outcomes.

Section 3 considers treatment and other operating costs for the calculation of distributions of **Gross Margins** for the Control treatment and nine alternative treatments applied variously in the field trials in the four districts. From among the nine alternative treatments, three were chosen for more detailed comparisons with the control (herbicide) treatment in each district. These show contrasts among treatments and between districts.

Section 4 focusses on financial consideration of all other costs at the level of an operational 50-ha vineyard over multiple ten-year periods. Using the treatment by treatment Gross Margins for each of the districts, **Risk Profiles** are generated. These contain long-run effects of different levels of opening debt at the farm level on the treatment outcomes.

Section 5 discusses the novel step-wise methods taken for several stages of preliminary results to reach the study's assessments of financial risk profiles on the basis of a 50 ha vineyard model under four levels of opening debt in each district for each treatment.

Section 6 concludes, noting limitations of the present analysis given the incomplete nature of our information so far on differences among treatments regarding **grape quality** (affecting prices, $/t), regarding changes in the under-vine **soil biome** (affecting vine health), and regarding efficacy of under-vine **weed suppression**.

2. GROSS REVENUE DISTRIBUTIONS

In this section, methods for determining gross revenue distributions over time are discussed as the first stage of our analysis, to produce the intermediate results forming the basis of the next section of the paper on Gross Margins.

Trial sites comparing a clean under-vine zone created using herbicides were established in randomised, replicated plots with nine alternative under-vine

treatments in one producing vineyard in each of four South Australian wine-grape districts. These focussed on the most widely grown vine variety in each district: Barossa, Shiraz; Eden Valley, Shiraz; Langhorne Creek, Cabernet Sauvignon and Riverland, Merlot. Useable yield data were obtained in the harvests of 2016 and 2017 for three of the districts but only for 2017 in Eden Valley.

The historical context of grape yield and price variations over time for the present analysis is represented by district yields and prices (calculated average purchase value) per tonne of the trial varieties in the four districts as reported in the ***SA Wine-grape Crush Survey*** by Wine Australia each year from 2006 through 2017. Over that period the consumer price index increased over 22%. Therefore, reported prices were adjusted to a constant (2017 dollar) basis (see Table 1). The consumer price indices (CPI) over that period for Adelaide (ABS 2017) were used for this purpose.

Taking the published grape harvest yield per ha for each year times that year's 2017 adjusted price results in a gross revenue value each year, as plotted for the four districts in Figure 1. Wide variations in gross revenues are evident in each district and these are taken to be representative of the common option of herbicide sprays for under-vine management, to define the Control treatment gross revenues in our analyses of the trials in each of the districts (Table 2). The variability in the Control gross revenues differ by district and these variations, as will be shown, are more or less correlated.

The 12-year yield and price sequences for the four districts were used to calculate the averages and standard deviations in each district. District means, variances and covariances among the yield and price sequences define the characteristic relationships among these measures. With these, it was possible to use the statistical program[1] **R** to simulate much longer sequences of random sets of values with similar statistical characteristics (averages, variances and covariances) to those found in the historical series. The extended series allows us to plot smoothed results over many more seasons than for the 12-year history. Examples are shown for 2,400 jointly-correlated (stochastic) random sets of simulated gross revenues from 2,400 sets of yields and prices for each district (Table 2). Here one may compare the simulated gross revenue values

[1] We wanted to draw samples from a specified multivariate normal distribution. Our approach was to combine Monte Carlo techniques with an eigen decomposition of the variance-covariance matrix of selected data. The statistical package **R** provides a convenient platform for these calculations. Specifically: we used the function 'mvrnorm' from the library MASS (https://cran.rproject.org/web/packages/MASS/MASS.pdf). We acknowledge the critical assistance provided by Dr David Luckett (Graham Centre) for this step of our analysis.

to those of the original 12-year historical series in terms of their statistical characteristics.

<<<< insert **Tables 1 and 2** about here >>>>

2,400 sets of simulated of gross revenues for the four districts (from which the samples shown in Table 2 were drawn) are plotted as Cumulative Distribution Functions (CDFs) in Figure 2 in terms of thousands of 2017 dollars per hectare. Here, considering the wide ranges of variation in gross revenues due to price and yield variations, one can appreciate the levels of riskiness in the vineyard business. Visually, Figure 3 captures the great year to year variability of gross revenues in the historical variations that are mimicked in the longer simulated series. Unsurprisingly, strong positive correlation (r=0.88) is captured between the Barossa and Eden Valley districts in gross revenue variations; these districts are geographically adjacent and therefore experience similar storm events and droughts through time; both grow Shiraz grapes and therefore also share a market. Positive correlation (r=0.74) in gross revenues can also be noted between Langhorne Creek Cab-sav and Riverland Merlot, though these districts are separated by over 150 km.

As mentioned above, the district yields and prices reported from 2006 through 2017 are taken to represent those associated with the most common method of under-vine management: one or more sprays of herbicide each year. Alternatives such as ploughing, cultivating and mowing, can be found around the world but are not part of the present study. Spraying under-vines has been relatively fast, easy, effective and is common across Australia as well as many other countries around the world; so much so that 35 confirmed reports of herbicide resistant weeds in grape vines have been documented around the world (Heap, 2018). Four of these confirmed reports are for multiple resistance to two herbicides; three further reports are for multiple resistance to three herbicides. A short review on these subjects is found in Nordblom *et al*. (2017).

<<<< insert **Figures 1, 2 and 3** about here >>>

3. GROSS MARGIN DISTRIBUTIONS

In this section, methods for determining Gross Margin distributions are shown, which produce results forming the basis of the subsequent section of the paper on Risk Profiles.

Production cost estimates have been provided by cooperating vineyard owners for each of the four districts. These are summarised for the Barossa farm in Table 3 (please see Appendix Tables 1, 2 and 3 for details on Eden Valley, Langhorne Creek and Riverland districts, respectively). We distinguish between the annual costs of the under-vine treatments: triticale straw mulch sourcing and spreading costs; seed and sowing costs of the living mulch treatments; and material and application costs for the herbicide treatment (Table 3). Also listed are the other annual operational costs common across all treatments, which are considered in calculating the sum of all annual vineyard operating costs for each. Obviously, there are differences in cost between the straw mulch (spread over 4 years) and annual herbicide treatments. In Table 3 the reader will also see there are differences among seed and seeding costs spread over 5 years for the alternative living mulches.

We assume the historical 2006-2017 yields and prices in the grape varieties of the four subject districts apply to the Control (herbicide only) under-vine treatments in the field trials. We further presume the **ratio** of the **average grape yield of an alternative under-vine treatment** to **that of the control (herbicide spray)** times **the gross revenue of the Control** will **give an estimate of the gross revenue of the alternative treatment**, assuming no differences in grape price per ton within a season and variety. The grape yield ratios found in the trial harvests of 2016 and 2017 are averaged at the top of Table 3 (and other district tables in the Appendix, except Eden Valley where only 2017 data are used).

Further, assuming these yield ratios hold across all periods, we recorded random draws from the baseline distributions of Control Gross revenues simulated in Figure 2 for the four districts, to define a probability distribution of gross revenues for each alternative under-vine treatment as its yield index times the Control Gross revenues. Table 2 indicates the generation of the 2,400 randomly drawn Control Gross revenues. Those for Barossa are carried into the 2nd column in the lower part of Table 3 (those for the other districts are likewise carried into Appendix tables 1 to 3). From each of the Control gross revenues the alternative treatment gross revenues are calculated (using the 2016 and 2017 yield indices), from which the annual operating costs of each under-vine alternative are subtracted to arrive at the distributions of **Gross Margin** values shown in the lower part of Table 3 for Barossa Shiraz (Appendix Tables 1, 2 and 3 for the other districts).

<<<< insert **Table 3** about here >>>

By design in Figure 4, the simulated Control treatment gross margin CDF for Barossa Shiraz is in the same relative position with the same median (50th percentile) values in both the 2016 and 2017 charts. Estimates of the three example alternative treatment CDFs shifted positions somewhat between the two years relative to the Control treatment. In 2016, Kasbah cocksfoot had lower gross margins than the others, which were clustered near the Control treatment. In 2017, the Control treatment had the lowest gross margin, with that of Kasbah cocksfoot being greater. The triticale mulch performed better, while the ryegrass/medic treatment was the best. Wide separation of results in 2017 contrasts with 2016.

At the Riverland district trial site, the Control treatment gave the highest gross margins in 2016 and second best in 2017 among the four treatments considered in Appendix Table 3 and Figure 4. The Kasbah cocksfoot treatment did least well in gross margins, assuming no differences in quality/price. The triticale straw mulch treatment was not included in the Riverland trial, but replaced with a living mulch of Governor ryegrass/Predator fescue (mix of perennial pasture grasses). This treatment did slightly better in 2017 but just better than Kasbah cocksfoot in 2016. However, our Botanal study of plant populations indicated this ryegrass/fescue treatment established poorly in the Riverland; thus, any yield differences are unlikely to be true treatment effects.

Eden Valley treatment grape yields, gross revenues, operating costs, and gross margins are simulated in Appendix Table 1. Only the results for 2017 are used as the 2016 yield results were compromised by delayed harvest due to a regional shortage of contract harvesters. In 2017 the ryegrass/medic treatment performed best, with median gross margins over $2,000/ha greater than the Control or triticale mulch treatments (Figure 5). The Kasbah cocksfoot performed only slightly better than the latter.

In Langhorne Creek results (Appendix Table 2), are available for two harvests, 2016 and 2017. Highest gross margins are calculated for the ryegrass/medic treatment in both seasons, above the Control treatment by a similar margin each time (Figure 5). The Kasbah cocksfoot had lower gross margins than the Control treatment in both seasons. Least consistent between seasons were the gross margins of triticale straw mulch … similar to the Control treatment in 2016 and to Kasbah cocksfoot in 2017.

<<<< insert **Figures 4 and 5** about here >>>>

In comparison to the gross revenue series plotted in Figure 2 for the four districts, the Control Gross margin series in Figure 6 differ by the subtraction of operating costs calculated for the Control treatments and three of the nine alternative treatments in Table 3 (and Appendix tables 1, 2 and 3).

Historical yield and price variations, and costs, differ among districts and vine varieties. Our simulated gross margin series sometime dip into negative values (below zero) in Figure 6, with the exception of Langhorne Creek in our examples. Analogous to Figure 2, which plots the CDFs of Control treatment **gross revenues** for each district, the CDFs of **gross margins** of the same Control treatments are given in Figure 6.

A median difference in gross margins of over $3,000/ha for the Control treatment (herbicide) between Eden Valley Shiraz and Riverland Merlot appears in Figure 6. Between these two extremes are the Control gross margin CDFs of Barossa Shiraz and Langhorne Creek Cab-sav.

<<<< insert **Figure 6** here >>>>

4. FARM FINANCIAL RISK PROFILES

We now have the basis for additional consideration of the farm financial costs: any recurring overhead costs, including interest on debts over time (such as those incurred in establishing the vineyard or in drought periods), machinery, depreciation and capital costs (the manager's wage, taxes on income).

Subtracting these costs from the treatment gross margins we arrive at the cash surplus, which we can now use to define long-run risk profiles for comparing under-vine treatments for a 50-ha vineyard in each of the four districts. These cash surpluses mirror the change in the bank balance resulting from each treatment, providing more complete whole-farm management information than is available from simple gross margin analysis.

To standardise measures across districts, we assume vineyards of 50-ha with equipment, fuel, repair and replacement costs of $8,820/year, additional recurring overhead costs (extra labour, vineyard repair and renewal) of $80K/year, manager's drawings of $120K/year, inflation of 3% per year on all the above costs, 6.5% interest payed on outstanding debt, 1.5% interest received on credit balances and 19% tax on farm income.

A ten-year (decadal) **cashflow budget** calculator is designed with five horizontal sectors in one worksheet, the first of which contains the above cost information. Below this is the key row (15) in the model where key cell **C15**

contains a code that randomly generates a number from 1 to 2,391, which is an address in a lookup table on the next page of 2,400 sets of four treatment Gross margins that were generated in Table 3 for Barossa Shiraz. The limit of 2,391 represents the maximum number of 'decades' (10 year sequences) that can be drawn from a simulated sequence of 2,400 years. The four values at that address and the following nine addresses are copied into the cashflow worksheet, 10 across, in four rows, eight lines apart. Those four rows of Gross margin values are those from the Control (herbicide) treatment and the three alternative treatments, now multiplied by 50 ha to represent a ten-year sample of price and yield variations in that district. This analytical setup is designed following that of Hutchings (2013), allowing repeated simulations of decadal cash margins with the Excel add-in, @RISK 7.5 (Palisade, 2017).

From these farm-level Gross margins are subtracted all the costs mentioned above as they accumulate over the decade, given a level of opening debt at one of four levels: Zero debt, -$250K, -$500K or -$1M debt. The level of opening debt is present in the cumulative cash balance in the first year and is subtracted from the closing cumulative cash balance at the end of 10 years to calculate the 'Decadal cash balance'. Of course, higher levels of opening debt require higher interest payments and increased borrowing in poor seasons, making it harder to achieve positive long-term cash margins. It is the burden of accumulating debts over time that amplify differences between treatments, largely because debit interest rates are three times greater than credit interest rates. Credit balances can also taxed, so that there is an inbuilt negative bias to long-term cash balances

In this model, decadal cashflow iterations can be repeated as quickly as new random numbers from 1 to 2,391 can be selected by cell **C15**. Running this model with the Excel add in @RISK completes 2,400 iterations in about 15 seconds. The brief explanation above may be sufficient for interpreting the results that follow, which are in terms of "distributions of decadal cash margins". More simply, we call these **Risk Profiles**. We now present the results district by district, each with four levels of opening debt.

<<<< insert **Figure 7. Barossa Shiraz Risk Profiles** about here >>>>

Here the reader is invited to compare the annual Gross Margin chart for Barossa (Figure 6) with the whole-farm risk profiles of the various treatments (Figure 7 A) with zero opening debt. Notice the horizontal axis expresses the ten-year closing bank balance of the vineyard in millions of dollars. The

Ryegrass/Medic and Straw mulch, which had higher gross margins than the other two treatments (Control and Kasbah Cocksfoot), have more than covered the whole-farm costs over time. The latter two treatments were able to cover the whole-farm costs in about 65% of decades. With $250K opening debt (Figure 7 B), the latter two treatments would only cover costs in about 50% of decades. Opening debt of $1M (Figure 7 D) would see the farm losing money in over 80% of decades, while the best treatments given the same opening debt would gain profits in 70 to 75 % of decades.

<<<< insert **Figure 8. Eden Valley Risk Profiles** about here >>>>

Comparisons are invited for Eden Valley's gross margins in Figure 6 with the risk profiles for that district in Figure 8. The spread between best and worst median gross margins is rather narrow and the best median gross margin is lower than the worst in the previous example (perhaps due to higher per hectare operational costs). With zero opening debt, subtracting the same 50-ha whole-farm costs from the lower gross margins for a decade shows all treatments to be loss-making; least so for the Ryegrass/Medic and Kasbah Cocksfoot treatments, but not enough so to save the farm. Increasing levels of opening debt send this vineyard into progressively deeper debt.

<<<< insert **Figure 9. Langhorne Creek Risk Profiles** about here >>>>

Here, readers are invited to compare Langhorne Creek gross margins (Figure 6) with the Langhorne Creek risk profiles in Figure 9. The median gross margin of the Control treatment is only slightly below that in Barossa. The Risk profile of the Control treatment in Langhorne Creek also shows the same tendency for accumulating debt with increasing levels of opening debt as in Barossa. Most promising among treatments in Langhorne Creek is that of Ryegrass/Medic, with an 85% chance of decadal profits given zero opening debts. Even with opening debt of $250K this treatment indicates a 70% chance of profitable operations.

<<<< insert **Figure 10. Riverland Risk Profiles** about here >>>>

The Riverland gross margins for the different treatments (Figure 6) may be compared with that district's Risk Profiles in Figure 10. Apparently most profitable among the under-vine treatments in the Riverland district is the Control (herbicide), with Predator Fescue and Ryegrass/Medic coming second and third (but recall, there is doubt these fescue results are true treatment results). Even with opening debts of $500K the Control treatment seems to indicate a financially viable vineyard. With opening debts of $250K the second

and third alternatives also would be viable. It is interesting to recall that Ryegrass/Medic and Triticale straw treatments were best in the Barossa case while the Control was the poorest option there.

5. DISCUSSION

The novel methodological steps in this paper included:

- Using the statistical characteristics of a 12-year historical series of grape yields and prices corrected for inflation for the four districts to generate a multivariate distribution from which to draw longer sample series with the same characteristics. This allowed us to define a set of baseline district by district distributions of 2400 gross revenues (prices x yields). We took these distributions to represent the Control (herbicide) treatment, providing the basis for simulating gross revenue distributions for the alternative treatments in each district.
- Comparing treatments in terms of probability distributions of their gross revenues and (after treatment and other operational costs) their Gross Margins. The Gross Margin is sometimes referred to as 'profit' though this is misleading as it does not account for other costs of sustaining a vineyard, including capital costs, drawings, taxes and interest.
- Introducing farm-financial risk considerations that are usually missed in typical analyses that stop with Gross Margins. Our Financial Risk analysis allows definition of Risk Profiles specific to a standard-sized 50-ha vineyard in each district and farm-level costs typical of these, including the risks of accumulating interest on debt when presented with several poor seasons in a row, or when starting with a low or high debt burden. A vineyard operation with a negative median decadal cash margin may not be financially viable. Our risk profiles indicate the **probability of a profitable vineyard** under different practices and conditions.

6. CONCLUSIONS

The surprising differences in financial rankings of the different treatments are 'explained' by district differences in yields, varieties and prices. However, these points do not explain the **causes** of yield differences, which are due to biological processes that are the main subject of the field experiments and biological measurements behind this work. There are unanswered questions that limit the present analysis given the incomplete nature of our information so far on differences among treatments regarding **grape quality** (affecting prices, $/t), regarding changes in the under-vine **soil biome** (affecting vine

health), and regarding efficacy of under-vine **weed suppression** by the different treatments.

The present analysis sheds light only on the economic and financial consequences (opportunities) that face vineyard managers. These results were obtained given assumptions of fixed ratios of treatment yields to Control yields, based on yield ratios observed in field trials over only two years. We also assumed constant grape quality across treatments at a given trial site in this preliminary analysis.

For grape prices we used the calculated average purchase value per tonne of the trial varieties as reported in the ***SA Winegrape Crush Survey*** reports (Wine Australia, 2006 – 2017). Thus, we have ignored the distributions of grape prices within a district for a variety, which change from year to year based on quality judgements in the market. As a result, we have certainly under-stated the profitabilities of vineyards consistently producing the highest quality grapes.

In only one of the districts (Riverland) did the Control (herbicide) treatment appear to be the best. In the other three districts the Control treatment appears only second best (Langhorne Creek), third best (Eden Valley) or the worst option (for Barossa).

Of course, one should be cautious about results from only two seasons at only one location in each district, even results that appear to be consistent over the two seasons. The evidence of highly volatile grape yields and prices in the study area is so pronounced that taking any two years as representative is somewhat naive. Nevertheless, our results are sufficiently provocative that we feel confident some alternatives to under-vine herbicide spraying may be financially superior to herbicide in some districts. The studies to date therefore justify investment in continued field studies on one hand and drawing farmers' attention to the alternatives where they seem best suited.

As of this writing, the European Union has only extended the licence for five years for glyphosate (herbicide) to be used in production of goods imported to the EU for human consumption. This lends a sense of urgency to the need for finding effective alternative under-vine treatments.

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The authors wish to acknowledge the financial support of grape-growers, winemakers and the Australian Government as administered by Wine Australia. This was crucially enabling for (1) the field trials carried out in South Australian vineyards by Chris Penfold, University of Adelaide; (2) the analysis of

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Table 1. Wine-grape district variety yields and prices adjusted for inflation, 2006-2017

District prices ($K/t) for trial area grape varieties 2006-2017 a						Inflation adjustment factors b			
	Barossa	Eden Valley	Lang Ck	Riverland		CPI all groups, Adelaide		CPI June 2017	
	Shiraz	Shiraz	Cab Sav	Merlot		Sept-2011 = 100		= 1.00	
2017	2.268	2.375	0.754	0.390		**Jun-17**	**109.2**	**1.000**	
2016	2.212	2.345	0.780	0.359		**Jun-16**	107.5	**0.984**	
2015	2.137	2.315	0.833	0.359		**Jun-15**	106.8	**0.978**	
2014	1.849	2.219	0.767	0.336		**Jun-14**	105.5	**0.966**	
2013	1.719	1.929	0.889	0.399		**Jun-13**	102.3	**0.937**	
2012	1.533	1.726	0.765	0.384		**Jun-12**	100.2	**0.918**	
2011	1.213	1.192	0.568	0.305		**Jun-11**	99	**0.907**	
2010	1.351	1.497	0.664	0.281		**Jun-10**	95.3	**0.873**	
2009	1.532	1.753	0.824	0.364		**Jun-09**	92.7	**0.849**	
2008	1.736	1.698	0.992	0.602		**Jun-08**	91.3	**0.836**	
2007	1.522	1.576	0.919	0.396		**Jun-07**	87.3	**0.799**	
2006	1.175	1.225	0.856	0.377		**Jun-06**	85.8	**0.786**	
AVERAGE	**1.687**	**1.821**	**0.801**	**0.379**				↓	
	←	←	←	←	←	←	←	←	
	↓	↓	↓	↓					

Prices adjusted for inflation over 2006-2017 sequence					District yields per ha for trial area grapes, 2006-2017 a, c			
	Barossa	**Eden Valley**	**Lang Ck**	**Riverland**	**Barossa**	**Eden Valley**	**Lang Ck**	**Riverland**
	Shiraz	**Shiraz**	**Cab Sav**	**Merlot**	**Shiraz**	**Shiraz**	**Cab Sav**	**Merlot**
	adj price	**adj price**	**adj price**	**adj price**	**Yield**	**Yield**	**Yield**	**Yield**
	($K/t)	**($K/t)**	**($K/t)**	**($K/t)**	**(t/ha)**	**(t/ha)**	**(t/ha)**	**(t/ha)**
2017	2.268	2.375	0.754	0.390	6.92	4.73	9.99	22.66
2016	2.247	2.382	0.792	0.364	4.74	3.25	9.73	21.32
2015	2.185	2.367	0.851	0.368	3.89	3.43	4.41	20.50
2014	1.914	2.297	0.794	0.348	3.67	2.00	8.15	20.31
2013	1.835	2.059	0.949	0.426	3.39	3.07	6.94	21.36
2012	1.671	1.881	0.834	0.419	4.22	3.70	7.71	20.09
2011	1.338	1.315	0.627	0.336	4.87	3.09	8.27	17.34
2010	1.548	1.715	0.761	0.322	5.53	4.10	6.16	16.82
2009	1.805	2.065	0.971	0.429	3.71	2.40	7.27	18.05
2008	2.077	2.031	1.187	0.720	5.30	5.13	7.89	22.22
2007	1.904	1.972	1.149	0.495	2.94	2.50	5.90	13.25
2006	1.496	1.559	1.089	0.480	6.98	4.83	10.82	25.14
AVERAGE	**1.857**	**2.001**	**0.897**	**0.425**	**4.681**	**3.519**	**7.770**	**19.922**
STDEV	**0.304**	**0.341**	**0.174**	**0.108**	**1.312**	**1.011**	**1.829**	**3.147**

a. Calculated from district-level reports on variety areas harvested and total values of grapes harvested, as found in the annual ***SA Winegrape Crush Surveys*** for 2006 through 2017.

b. Inflation adjustment factors were derived from the Australian Bureau of Statistics CPI for all groups of goods at Adelaide.

c. See Table 2 and Figure 1 for gross revenue values ($K/ha) resulting from multiplication of district variety yields per hectare (t/ha) with the corresponding district variety price adjusted for inflation ($K/t) for each year in the present table.

Table 2. Historical gross revenues from 12 harvests, transformed to 2400 stochastic harvest gross revenues

	Historical GROSS REVENUE ($K/ha)					**Simulated GROSS REVENUE ($K/ha)**			
	Yield x Price adjusted for inflation, 2006-2017 [a]					**for 2400 seasons**			
Harvest year	Barossa Shiraz	Eden V. Shiraz	Lang Ck Cab-Sav	Riverland Merlot	**Sim Harvest**	Barossa Shiraz	Eden V. Shiraz	Lang Ck Cab-Sav	Riverland Merlot
2017	15.688	11.223	7.530	8.843	**1**	11.269	7.971	8.419	8.347
2016	10.644	7.739	7.706	7.765	**2**	7.479	6.697	5.256	6.689
2015	8.498	8.111	3.751	7.535	**3**	10.165	7.808	9.343	10.437
2014	7.033	4.593	6.469	7.062	**4**	5.889	3.983	7.341	6.313
2013	6.224	6.316	6.589	9.098	**5**	10.895	11.124	9.925	17.352
2012	7.050	6.967	6.430	8.415	**6**	15.693	12.243	6.950	8.665
2011	6.522	4.067	5.183	5.828	**:**	**:**	**:**	**:**	**:**
2010	8.563	7.027	4.686	5.423	**2396**	8.137	8.319	7.912	13.525
2009	6.696	4.946	7.059	7.750	**2397**	8.981	8.729	7.237	13.452
2008	11.009	10.426	9.364	16.001	2398	12.796	9.971	4.588	7.818
2007	5.595	4.926	6.783	6.563	**2399**	5.795	6.992	3.477	7.138
2006	10.446	7.536	11.784	12.069	**2400**	8.947	7.292	12.200	13.772
AVERAGE	**8.664**	**6.990**	**6.945**	**8.529**	**AVERAGE**	**8.671**	**6.983**	**6.930**	**8.530**
STDEV	**2.877**	**2.237**	**2.116**	**2.922**	**STDEV**	**2.733**	**2.190**	**2.067**	**2.787**

Correlations among historical 2006-2017 series

	Barossa Shiraz	*Eden V. Shiraz*	*Lang Ck Cab-Sav*	*Riverland Merlot*
Barossa Shiraz	1			
Eden V. Shiraz	0.880	1		
Lang Ck Cab-Sav	0.406	0.326	1	
Riverland Merlot	0.428	0.609	0.743	1

Correlations among simulated series

	Barossa Shiraz	*Eden V. Shiraz*	*Lang Ck Cab-Sav*	*Riverland Merlot*
Barossa Shiraz	1			
Eden V. Shiraz	0.864	1		
Lang Ck Cab-Sav	0.428	0.355	1	
Riverland Merlot	0.422	0.628	0.735	1

Covariances

	Barossa Shiraz	*Eden V. Shiraz*	*Lang Ck Cab-Sav*	*Riverland Merlot*
Barossa Shiraz	7.589			
Eden V. Shiraz	5.189	4.585		
Lang Ck Cab-Sav	2.266	1.415	4.104	
Riverland Merlot	3.295	3.651	4.212	7.828

Covariances

	Barossa Shiraz	*Eden V. Shiraz*	*Lang Ck Cab-Sav*	*Riverland Merlot*
Barossa Shiraz	7.464			
Eden V. Shiraz	5.167	4.796		
Lang Ck Cab-Sav	2.417	1.608	4.269	
Riverland Merlot	3.212	3.831	4.233	7.764

a **Source:** Adjusted prices x district yields each year from 2006 through 2017 from Table 1.

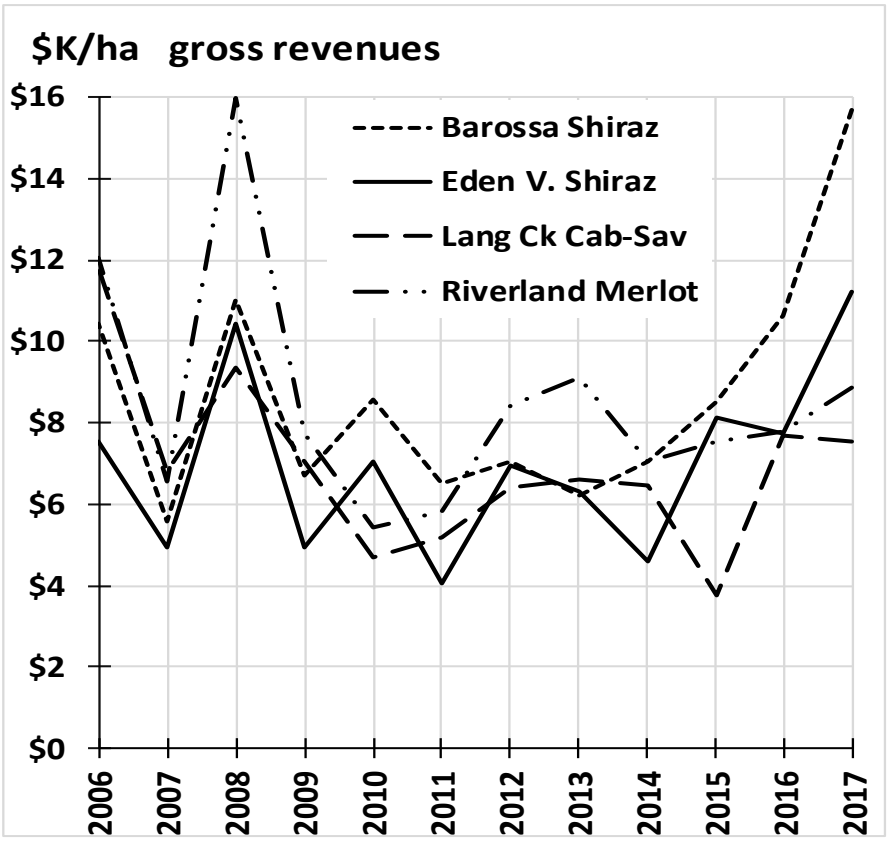


Figure 1. District and variety specific grape harvest Gross Revenues, yields x prices adjusted for inflation (Table 2 values).

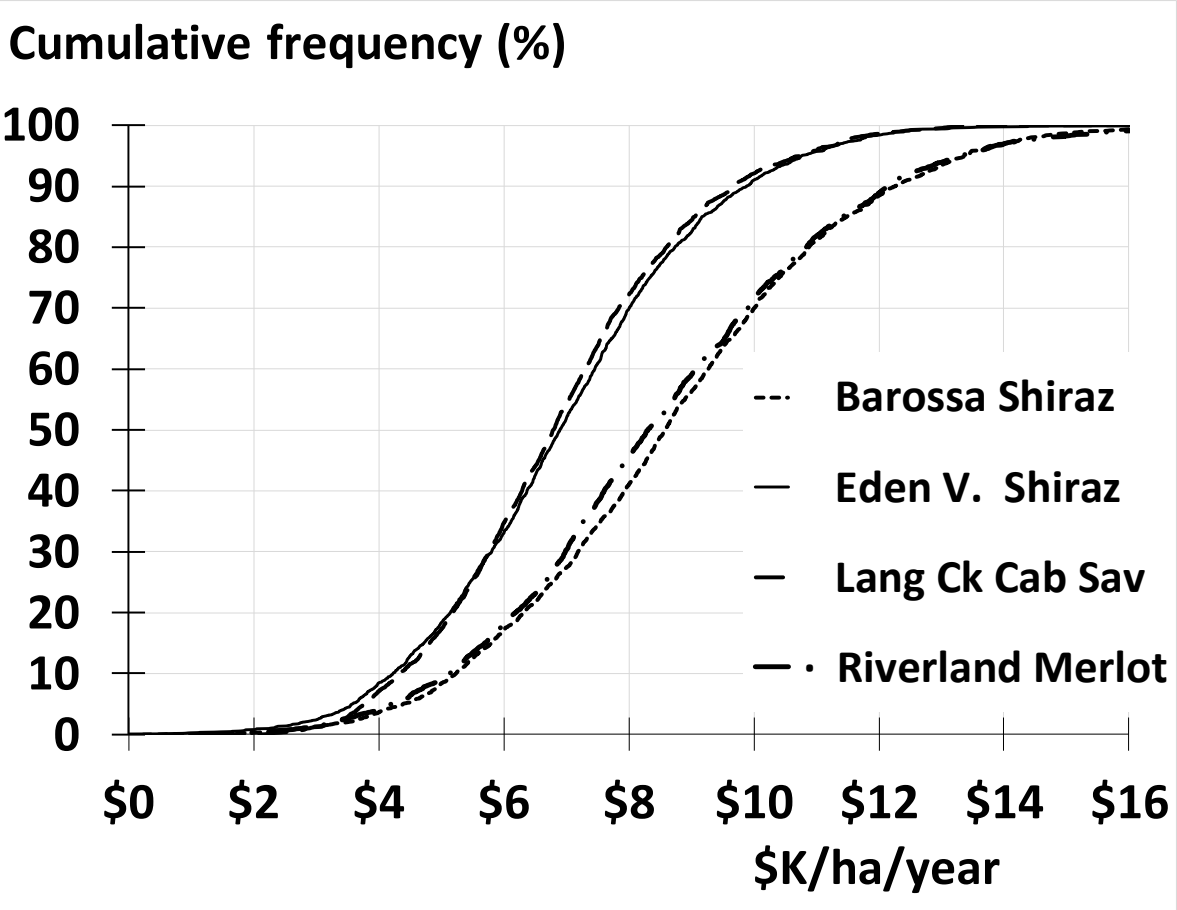


Figure 2. Gross revenues (yields x prices) for wine-grape harvests in four South Australian districts over the 2006-2017 period, expressed as cumulative distribution functions (CDFs) in constant 2017 dollars. In the present study, these CDFs are taken to represent the control (herbicide) treatment baselines for their respective districts, against which differences in gross revenues of alternative under-vine treatments are measured.
Source: simulations based on data in Tables 1 and 2.

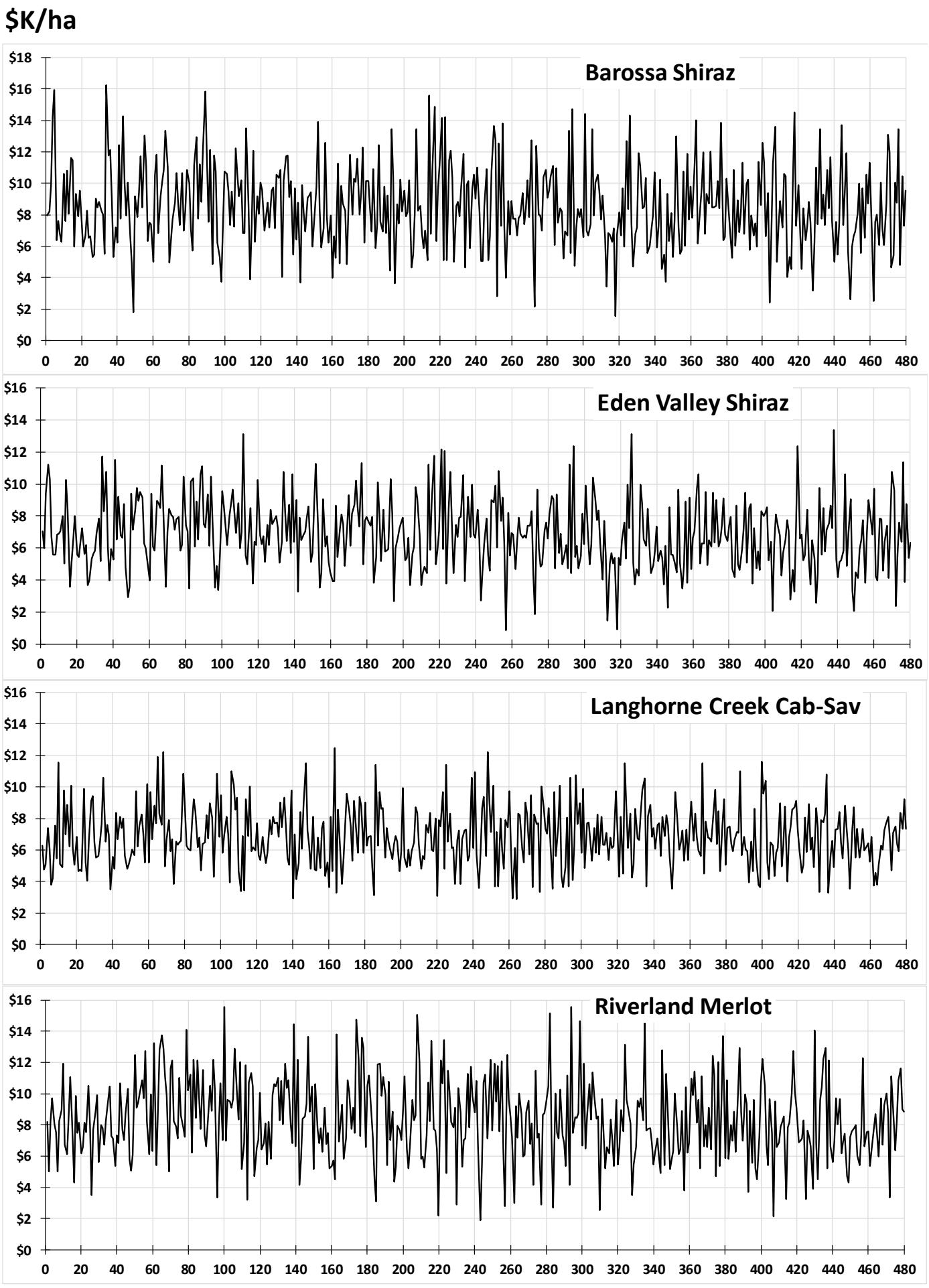


Figure 3. District/variety gross revenues, price x yields (**$K/ha**) across 480 seasons simulated for under-vine Control treatment (herbicide).

Table 3. Barossa Shiraz yields of treatments relative to herbicide (control) yields times 2400 control gross revenues to calculate treatment gross revenues, and subtracting annual under-vine treatment and other operating costs to calculate treatment Gross Margins for 2400 simulated harvests.

Barossa GR-Costs → GMs	Barossa Treatment yields wrt Control	01.Triticale mulch	02. Kasbah cocksfoot	03. Wallaby grass	04. Zorro fescue	05. Cavalier/Bindaroo medic	06. Angel/Sultan medic	07. Ryegrass/Burr medic	08. Sheep fescue/Strawberry clover	09. Mintaro subclover/Prima gland	**10. Control (herbicide)**
2016+17 Yield Indices/2		**1.222**	**0.985**	**0.953**	**0.969**	**1.028**	**1.169**	**1.159**	**1.047**	**0.966**	1
UNDER-VINE ANNUAL COSTS ($/ha)											
with Straw sourced & spread, $3K/4 yrs		**$750**									
with Seed & seeding /ha each 5 yrs			**$40**	**$175**	**$31**	**$47**	**$47**	**$99**	**$72**	**$74**	
with Herbicide & application / ha / yr											**$333**
OTHER ANNUAL VINEYARD COSTS ($/ha)											
Fungicide material costs		$95	$95	$95	$95	$95	$95	$95	$95	$95	**$95**
Fungicide application costs		$375	$375	$375	$375	$375	$375	$375	$375	$375	**$375**
Mowing mid-row		$150	$150	$150	$150	$150	$150	$150	$150	$150	**$150**
Fertilizer (MAP soluble)		$32	$32	$32	$32	$32	$32	$32	$32	$32	**$32**
Pruning and hedging vines		$1,339	$1,339	$1,339	$1,339	$1,339	$1,339	$1,339	$1,339	$1,339	**$1,339**
Irrigation (0.8 ML @ $700/ML)		$560	$560	$560	$560	$560	$560	$560	$560	$560	**$560**
Harvesting (108 min/ha @ $445/hr)		$800	$800	$800	$800	$800	$800	$800	$800	$800	**$800**
SUM ANNUAL OPERATIONAL COSTS ($K/ha)		**$4.10**	**$3.39**	**$3.52**	**$3.38**	**$3.40**	**$3.40**	**$3.45**	**$3.42**	**$3.42**	**$3.68**
	(Herbicide)			**Treatment Gross Margins ($K/ha)**							
Barossa control:	**GR sim ($K/ha)**	**BGM01**	**BGM02**	**BGM03**	**BGM04**	**BGM05**	**BGM06**	**BGM07**	**BGM08**	**BGM09**	**BGM10**
1	**11.269**	$9.672	$7.705	$7.210	$7.536	$8.192	$9.776	$9.609	$8.375	$7.464	**$7.586**
2	**7.479**	$5.040	$3.974	$3.600	$3.865	$4.294	$5.346	$5.217	$4.407	$3.803	**$3.796**
3	**10.165**	$8.323	$6.619	$6.159	$6.467	$7.057	$8.486	$8.330	$7.219	$6.398	**$6.482**
4	**5.889**	$3.097	$2.408	$2.085	$2.325	$2.659	$3.487	$3.375	$2.743	$2.266	**$2.206**
5	**10.895**	$9.215	$7.337	$6.854	$7.174	$7.807	$9.339	$9.175	$7.983	$7.103	**$7.212**
6	**15.693**	$15.078	$12.062	$11.425	$11.822	$12.741	$14.947	$14.735	$13.006	$11.739	**$12.010**
↓	↓										↓
2396	**8.137**	$5.844	$4.622	$4.227	$4.502	$4.971	$6.115	$5.979	$5.096	$4.438	**$4.454**
2397	**8.981**	$6.875	$5.452	$5.030	$5.320	$5.839	$7.101	$6.957	$5.979	$5.253	**$5.298**
2398	**12.796**	$11.538	$9.209	$8.665	$9.016	$9.762	$11.561	$11.378	$9.973	$8.940	**$9.113**
2399	**5.795**	$2.982	$2.315	$1.995	$2.233	$2.562	$3.377	$3.265	$2.644	$2.175	**$2.112**
2400	**8.947**	$6.834	$5.420	$4.999	$5.287	$5.804	$7.062	$6.918	$5.944	$5.221	**$5.264**
Averages	**8.671**	**6.497**	**5.148**	**4.736**	**5.020**	**5.521**	**6.740**	**6.599**	**5.656**	**4.955**	**4.988**
Stdev	**2.733**	**3.339**	**2.691**	**2.603**	**2.647**	**2.810**	**3.194**	**3.166**	**2.860**	**2.640**	**2.733**

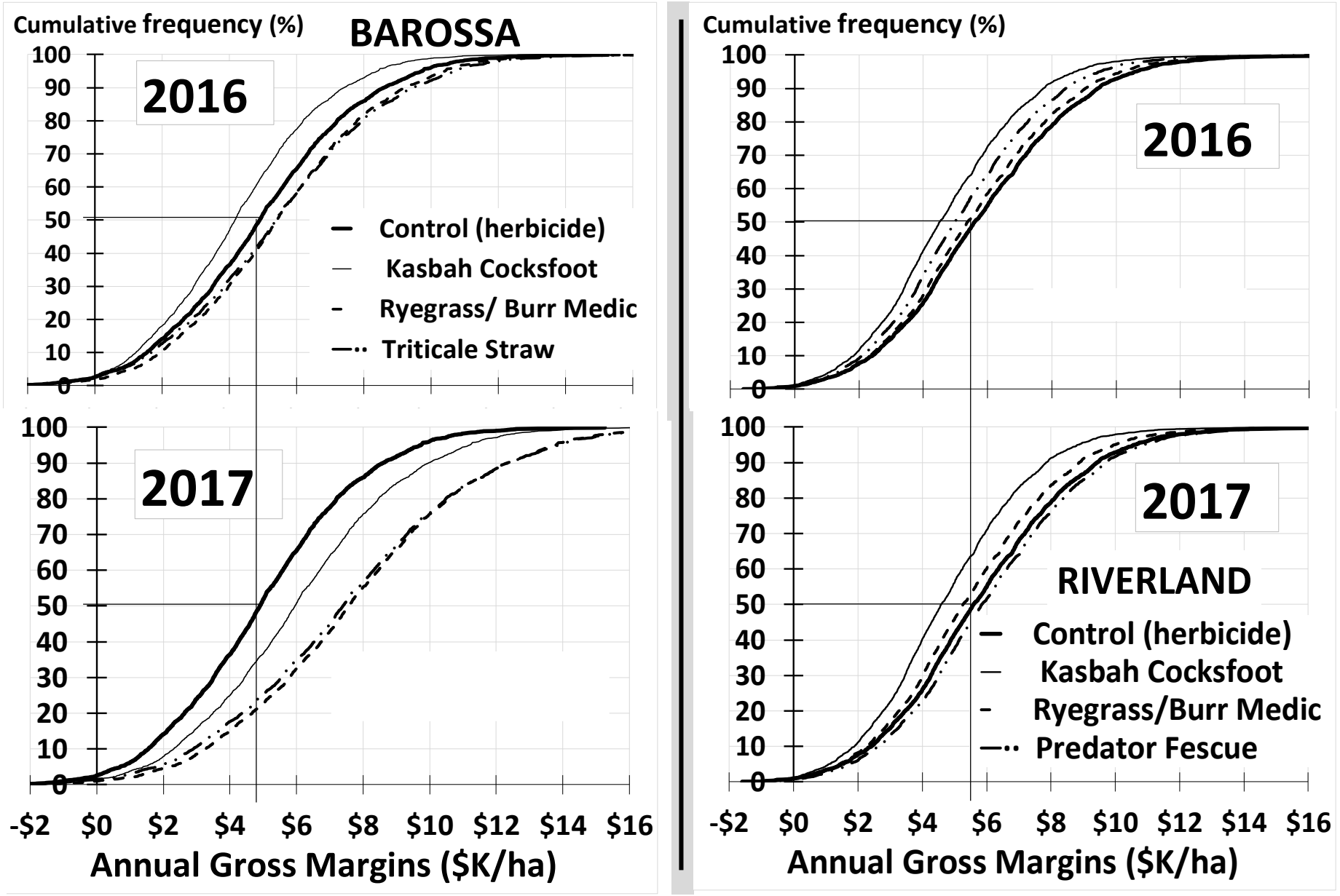


Figure 4. Barossa and Riverland Gross Margins of four under-vine treatments in 2016 and 2017 as CDFs. Note: distributions of Gross Margins of alternative treatments vary from year to year relative the Control distributions, assumed constant over time.

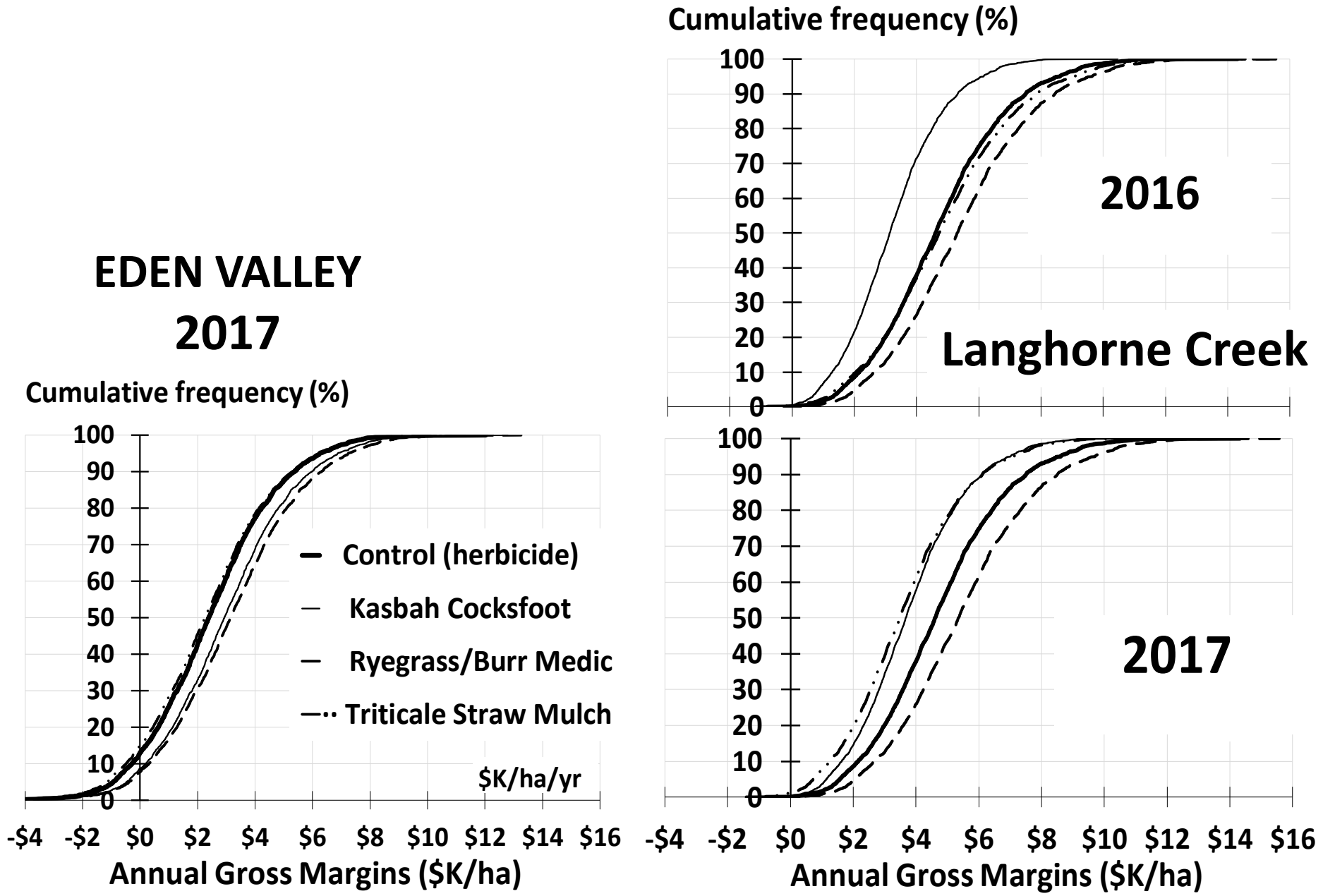


Figure 5. Eden Valley and Langhorne Creek Gross Margins of four under-vine treatments in 2016 & 2017 as CDFs. Note: distributions of Gross Margins of alternative treatments vary from year to year relative to the Control distributions, assumed constant over time

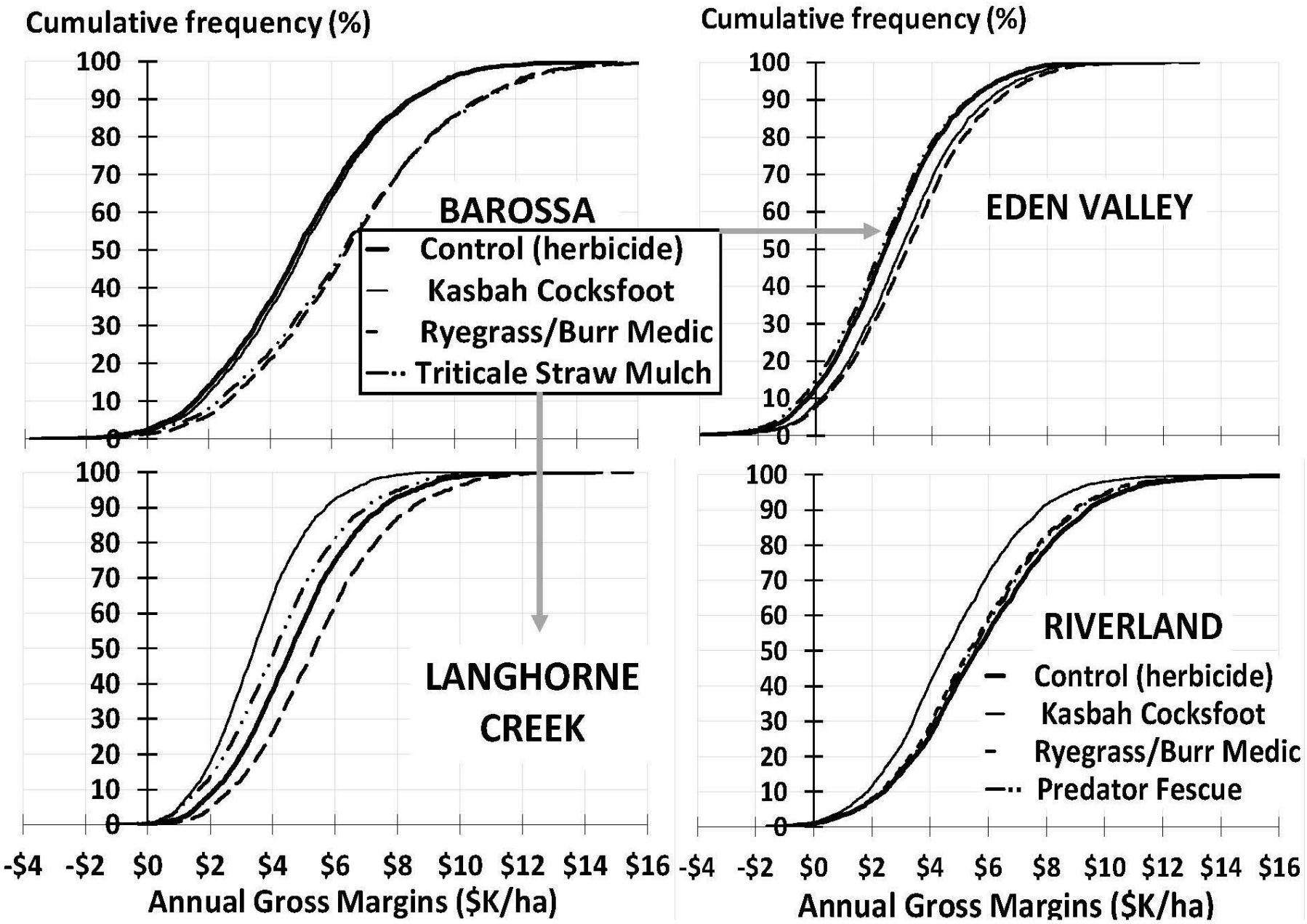


Figure 6. Mean 2016/2017 distributions of gross margins by district and under-vine treatment.

Sources: Barossa, Figure 4 & Table 3; Eden Valley, Figure 5 & Appendix Table 1 (2017 only); Langhorne Creek, Figure 5 & Appendix Table 2; Riverland, Figure 4 & Appendix Table 3.

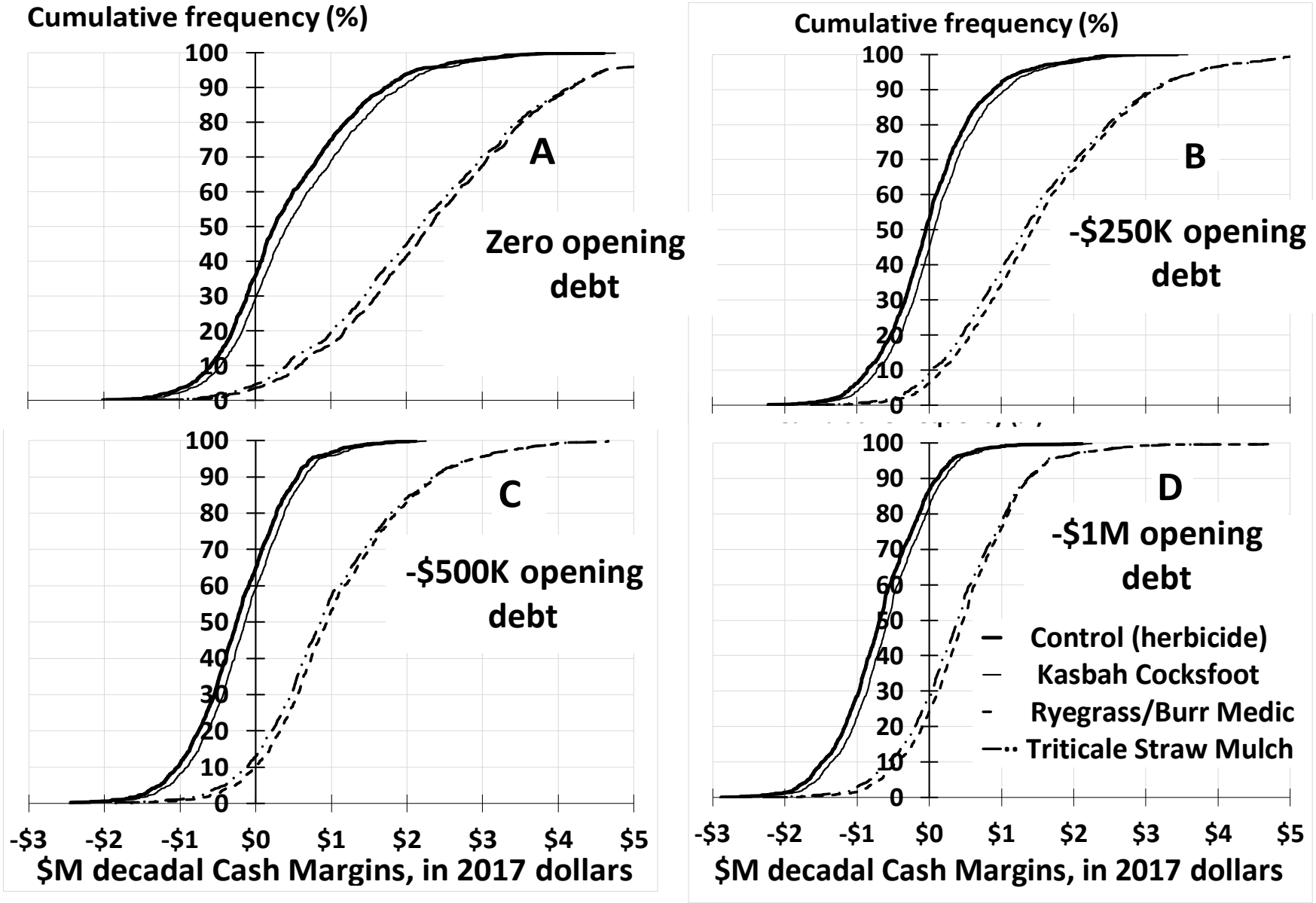


Figure 7. Barossa Valley, financial Risk Profiles for a 50-ha vineyard with four under-vine treatments given four opening debt levels.

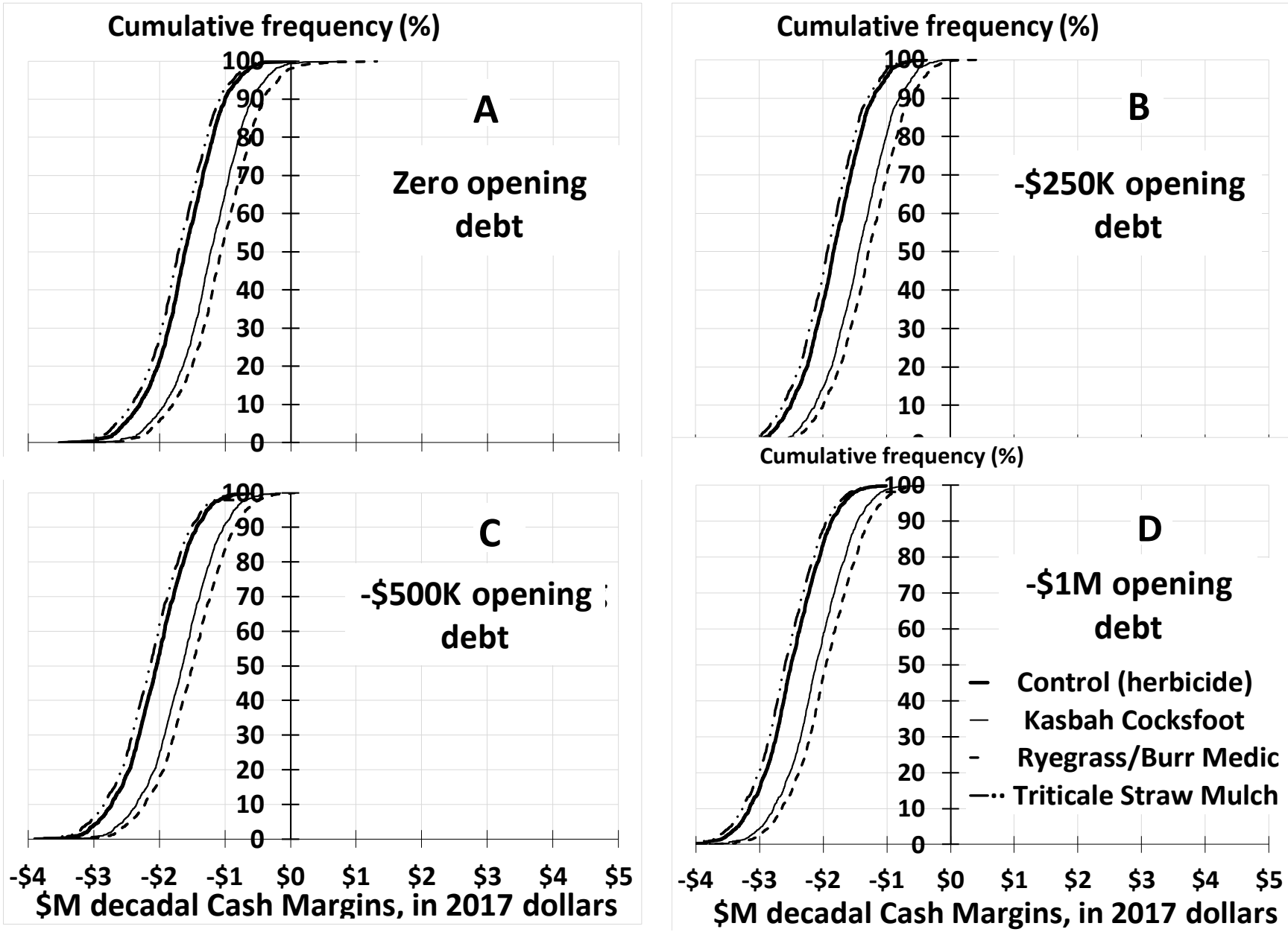


Figure 8. Eden Valley, financial Risk Profiles for a 50-ha vineyard with four under-vine treatments given four opening debt levels.

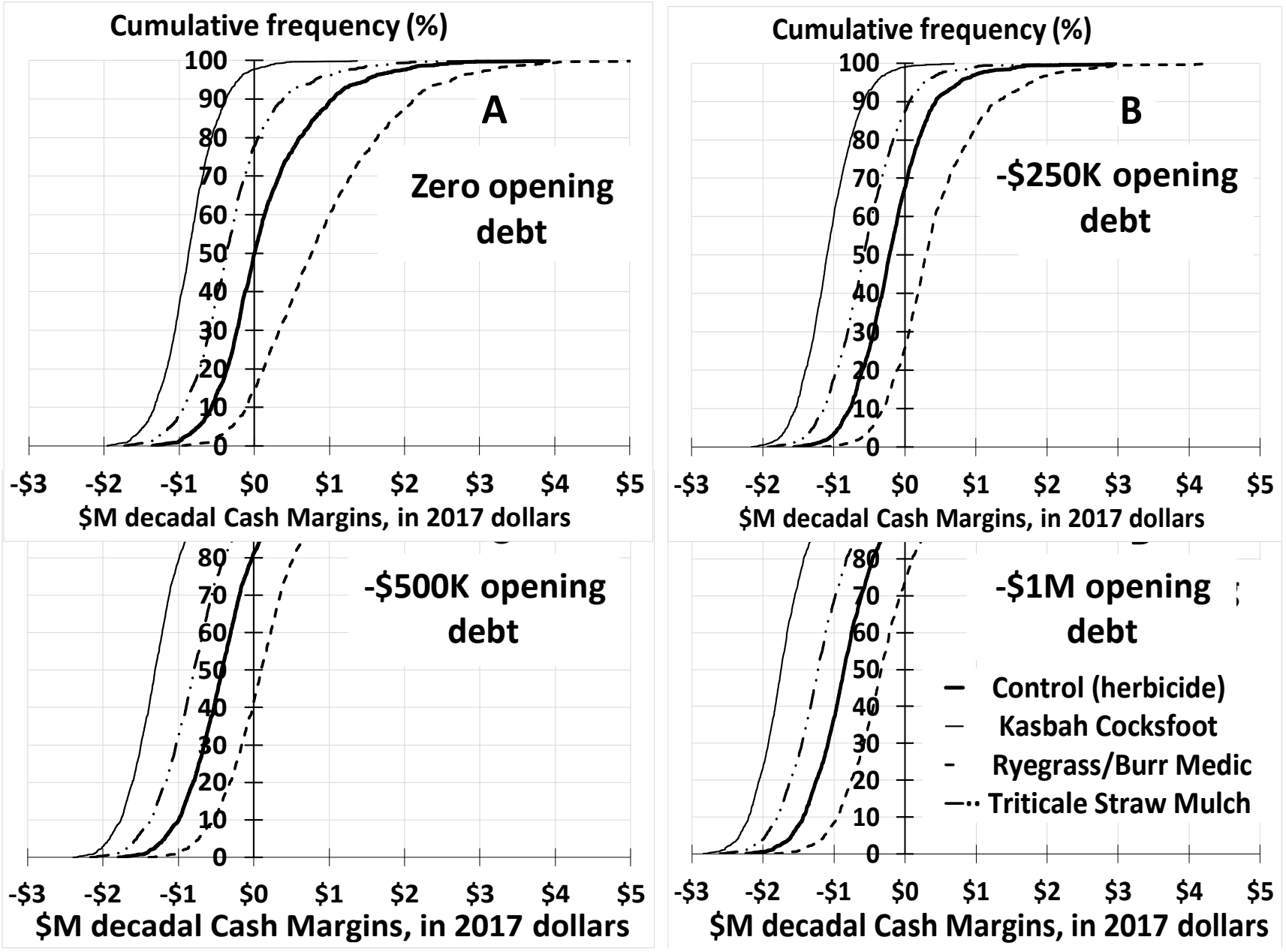


Figure 9. Langhorne Creek, financial Risk Profiles for a 50-ha vineyard with four under-vine treatments given four opening debt levels.

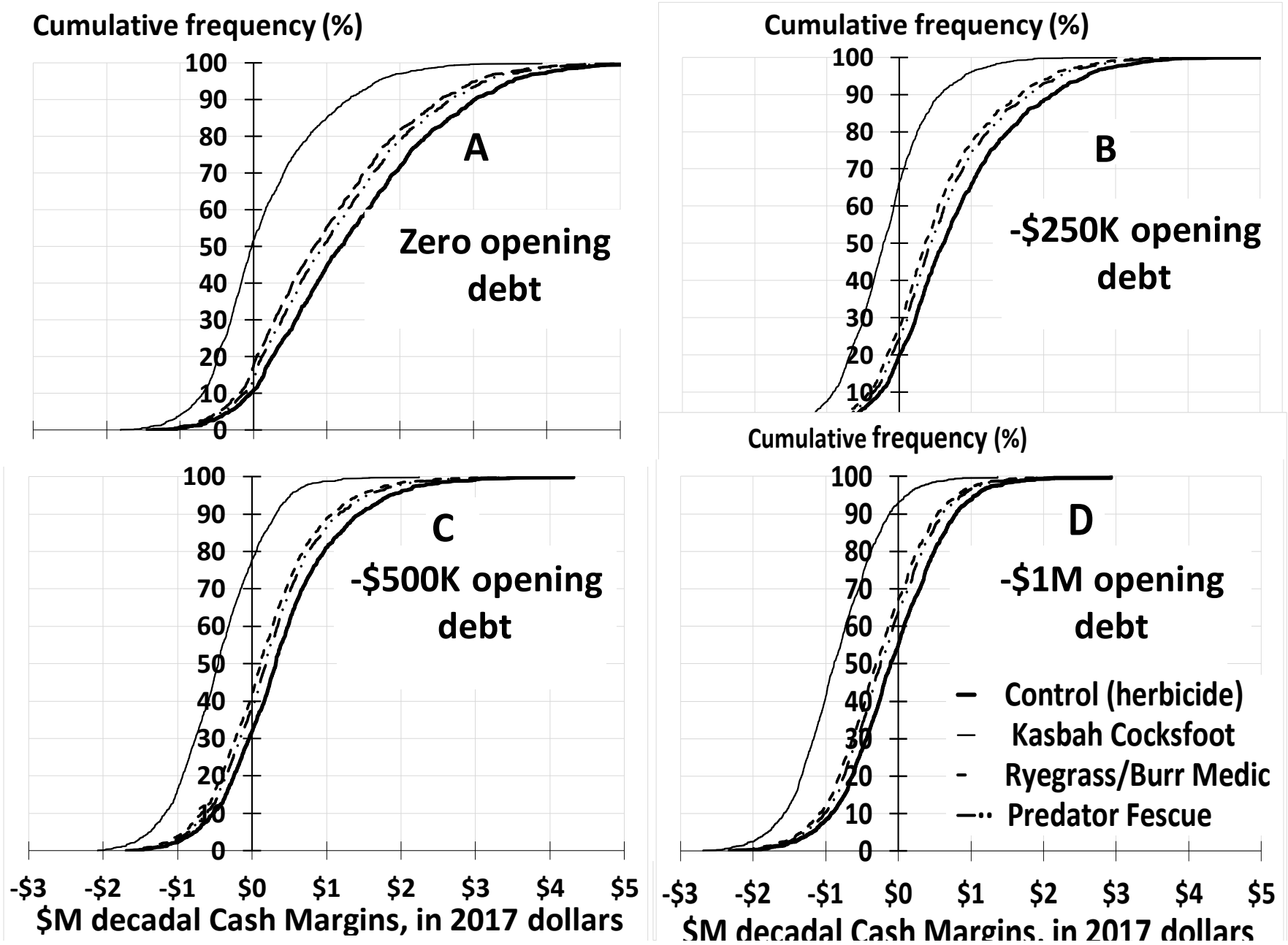


Figure 10. Riverland, financial Risk Profiles for a 50-ha vineyard with four under-vine treatments given four opening debt levels.

Appendix Table 1. Eden Valley Shiraz yields of treatments relative to herbicide (control) yields times 2400 control gross revenues to calculate treatment gross revenues, and subtracting annual under-vine treatment and other operating costs to calculate treatment Gross Margins for 2400 simulated harvests. Only the 2017 harvest data used here.

Eden V. GR-Costs → GMs	Eden Valley Treatment yields wrt Control	01.Triticale mulch	02. Kasbah cocksfoot	03. Wallaby grass	04. Zorro fescue	05. Cavalier/Bindaroo medic	06. Angel/Sultan medic	07. Ryegrass/Burr medic	08. Sheep fescue/Strawberry clover	09. Mintaro subclover/Prima gland	10. Control (herbicide)
2017 Yield Index		1.026	1.022	0.787	1.112	1.039	1.293	1.061	0.877	0.776	1.000
UNDER-VINE ANNUAL COSTS ($/ha)											
with Straw sourced & spread, $3K/4 yrs		$750									
with Seed & seeding /ha each 5 yrs			$40	$175	$31	$47	$47	$99	$72	$74	
with Herbicide & application / ha / yr											$437
OTHER ANNUAL VINEYARD COSTS ($/ha)											
Fungicide material costs		$142	$142	$142	$142	$142	$142	$142	$142	$142	$142
Fungicide application costs		$900	$900	$900	$900	$900	$900	$900	$900	$900	$900
Mowing mid-row		$300	$300	$300	$300	$300	$300	$300	$300	$300	$300
Fertilizer (MAP soluble)		$32	$32	$32	$32	$32	$32	$32	$32	$32	$32
Pruning and hedging vines		$1,339	$1,339	$1,339	$1,339	$1,339	$1,339	$1,339	$1,339	$1,339	$1,339
Irrigation (0.8 ML @ $700/ML)		$560	$560	$560	$560	$560	$560	$560	$560	$560	$560
Harvesting (108 min/ha @ $445/hr)		$800	$800	$800	$800	$800	$800	$800	$800	$800	$800
SUM ANNUAL OPERATIONAL COSTS ($K/ha)		$4.82	$4.11	$4.25	$4.10	$4.12	$4.12	$4.17	$4.14	$4.15	$4.51
	Gross Revenue sims (Herbicide)			Treatment Gross Margins ($K/ha)							
Eden V. control:	($K/ha)	EGM01	EGM02	EGM03	EGM04	EGM05	EGM06	EGM07	EGM08	EGM09	EGM10
1	7.97	3.35	4.03	2.03	4.76	4.17	6.19	4.29	2.85	2.04	3.46
2	6.70	2.05	2.73	1.02	3.35	2.84	4.54	2.94	1.73	1.05	2.19
3	7.81	3.18	3.87	1.90	4.58	4.00	5.98	4.11	2.71	1.91	3.30
4	3.98	-0.74	-0.04	-1.11	0.33	0.02	1.03	0.06	-0.65	-1.06	-0.53
5	11.12	6.59	7.25	4.51	8.27	7.44	10.27	7.63	5.62	4.49	6.61
6	12.24	7.73	8.40	5.39	9.52	8.61	11.71	8.82	6.60	5.36	7.73
↓	↓										↓
2395	5.28	0.59	1.28	-0.09	1.77	1.37	2.71	1.43	0.49	-0.05	0.77
2396	8.32	3.71	4.39	2.30	5.15	4.53	6.64	4.66	3.16	2.31	3.81
2397	8.73	4.13	4.81	2.62	5.61	4.95	7.17	5.09	3.52	2.63	4.22
2398	9.97	5.40	6.08	3.60	6.99	6.24	8.78	6.41	4.60	3.59	5.46
2399	6.99	2.35	3.03	1.26	3.67	3.15	4.92	3.25	1.99	1.28	2.48
2400	7.29	2.66	3.34	1.49	4.01	3.46	5.31	3.57	2.25	1.51	2.78
Average	6.98	2.34	3.02	1.25	3.66	3.14	4.91	3.24	1.98	1.27	2.47
STDEV	2.19	2.25	2.24	1.72	2.44	2.28	2.83	2.32	1.92	1.70	2.19

Appendix Table 2. Langhorne Creek Cab-sav yields of treatments relative to herbicide (control) yields times 2400 control gross revenues to calculate treatment gross revenues, and subtracting annual under-vine treatment and other operating costs to calculate treatment Gross Margins for 2400 simulated harvests.

Langhorne Ck GR-Costs → GMs	Barossa Treatment yields wrt Control	01. Triticale straw mulch	02. Kasbah cocksfoot (perennial grass)	03. Wallaby grass (native perennial)	04. Zorro fescue (annual grass)	05. Cavalier burr/Bindaroo button medic	06. Angel strand/Sultan barrel medic	07. Ryegrass/Burr medic	08. Predator fescue/Palestine strawberry clover	09. Predator/Governor fescue mix	10. Control (herbicide)
average of 2016 and 2017 Yield Indices		1.001	0.794	0.969	0.839	0.983	1.101	1.086	0.751	0.846	1.000
UNDER-VINE ANNUAL COSTS ($/ha)											
with Straw sourced & spread, $3K/4 yrs		$750									
with Seed & seeding /ha each 5 yrs			$40	$175	$31	$47	$47	$99	$50	$50	
with Herbicide & application / ha / yr											$232
OTHER ANNUAL VINEYARD COSTS ($/ha)											
Fungicide material costs		$193	$193	$193	$193	$193	$193	$193	$193	$193	$193
Fungicide application costs		$315	$315	$315	$315	$315	$315	$315	$315	$315	$315
Mowing mid-row		$180	$180	$180	$180	$180	$180	$180	$180	$180	$180
Fertilizer (UAN)		$15	$15	$15	$15	$15	$15	$15	$15	$15	$15
Pruning and hedging vines		$160	$160	$160	$160	$160	$160	$160	$160	$160	$160
Irrigation (3.2 ML @ $530)		$530	$530	$530	$530	$530	$530	$530	$530	$530	$530
Harvesting		$550	$550	$550	$550	$550	$550	$550	$550	$550	$550
SUM ANNUAL OPERATIONAL COSTS ($K/ha)		$2.69	$1.98	$2.12	$1.97	$1.99	$1.99	$2.04	$1.99	$1.99	$2.18
	Gross Revenue sims (Herbicide)			Treatment Gross Margins ($K/ha/year)							
Langhorne Ck control:	CDF ($K/ha)	LGM01	LGM02	LGM03	LGM04	LGM05	LGM06	LGM07	LGM08	LGM09	LGM10
1	8.42	$5.73	$4.70	$6.04	$5.09	$6.28	$7.28	$7.10	$4.33	$5.13	$6.24
2	5.26	$2.57	$2.19	$2.98	$2.43	$3.17	$3.79	$3.67	$1.95	$2.45	$3.08
3	9.34	$6.66	$5.44	$6.94	$5.86	$7.19	$8.29	$8.10	$5.02	$5.91	$7.17
4	7.34	$4.65	$3.85	$5.00	$4.18	$5.22	$6.09	$5.93	$3.52	$4.22	$5.17
5	9.93	$7.24	$5.90	$7.50	$6.35	$7.76	$8.93	$8.74	$5.46	$6.40	$7.75
6	6.95	$4.26	$3.53	$4.62	$3.86	$4.84	$5.66	$5.51	$3.23	$3.88	$4.77
↓	↓										↓
2395	8.06	$5.37	$4.42	$5.69	$4.79	$5.93	$6.88	$6.71	$4.06	$4.82	$5.88
2396	7.91	$5.23	$4.30	$5.55	$4.66	$5.79	$6.72	$6.55	$3.95	$4.70	$5.74
2397	7.24	$4.55	$3.76	$4.90	$4.10	$5.12	$5.98	$5.82	$3.44	$4.13	$5.06
2398	4.59	$1.90	$1.66	$2.33	$1.88	$2.52	$3.06	$2.94	$1.45	$1.89	$2.41
2399	3.48	$0.79	$0.78	$1.25	$0.94	$1.43	$1.84	$1.73	$0.62	$0.95	$1.30
2400	12.20	$9.52	$7.70	$9.71	$8.26	$10.00	$11.44	$11.21	$7.17	$8.32	$10.02
Average	6.93	$4.24	$3.52	$4.60	$3.84	$4.82	$5.64	$5.48	$3.21	$3.87	$4.75
STDEV	2.07	$2.07	$1.64	$2.00	$1.73	$2.03	$2.27	$2.24	$1.55	$1.75	$2.07

Appendix Table 3. Riverland Merlot yields of treatments relative to herbicide (control) yields times 2400 control gross revenues to calculate treatment gross revenues, and subtracting annual under-vine treatment and other operating costs to calculate treatment Gross Margins for 2400 simulated harvests.

Riverland GR-Costs → GMs	Riverland Treatment yields wrt Control	01. Governor/Predator fescues	02. Kasbah cocksfoot	03. Wallaby grass	04. Zorro Fescue	05. Cavalier/Bindaroo medic	06. Angel/Sultan medic	07. Ryegrass/Burr medic	08. Atriplex semibaccata	09. Toreador disc medic	10. Control (herbicide)
average of 2016 and 17 Yield Indices		0.952	0.846	0.946	0.965	0.967	0.933	0.948	0.941	0.952	1.000
UNDER-VINE ANNUAL COSTS ($/ha)											
with no Straw sourced & spread		na									
with Seed & seeding /ha each 5 yrs		$50	$40	$175	$31	$47	$47	$99	$50	$50	
with Herbicide & application / ha / yr											$259
OTHER ANNUAL VINEYARD COSTS ($/ha)											
Fungicide material costs		$170	$170	$170	$170	$170	$170	$170	$170	$170	$170
Fungicide application costs		$280	$280	$280	$280	$280	$280	$280	$280	$280	$280
Mowing mid-row		$40	$41	$42	$43	$44	$45	$46	$47	$48	$49
Fertilizer (MAP soluble)		$50	$50	$50	$50	$50	$50	$50	$50	$50	$50
Pruning and hedging vines		$160	$160	$160	$160	$160	$160	$160	$160	$160	$160
Irrigation (6.0 ML @ $1000)		$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000	$1,000
Harvesting		$750	$750	$750	$750	$750	$750	$750	$750	$750	$750
SUM ANNUAL OPERATIONAL COSTS ($K/ha)		$2.50	$2.49	$2.63	$2.48	$2.50	$2.50	$2.56	$2.51	$2.51	$2.72
	Gross Revenue sims (Herbicide)			Treatment Gross Margins ($K/ha/year)							
Riverland control:	($K/ha)	RGM01	RGM02	RGM03	RGM04	RGM05	RGM06	RGM07	RGM08	RGM09	RGM10
1	8.35	5.45	4.57	5.27	5.57	5.57	5.29	5.36	5.35	5.44	5.63
2	6.69	3.87	3.17	3.70	3.97	3.96	3.74	3.79	3.79	3.86	3.97
3	10.44	7.44	6.34	7.25	7.58	7.59	7.24	7.34	7.32	7.43	7.72
4	6.31	3.51	2.85	3.35	3.61	3.60	3.39	3.43	3.44	3.50	3.59
5	17.35	14.02	12.20	13.79	14.26	14.27	13.69	13.89	13.83	14.01	14.63
6	8.67	5.75	4.84	5.57	5.88	5.87	5.59	5.66	5.65	5.74	5.95
↓	↓										↓
2395	8.91	5.99	5.05	5.80	6.11	6.11	5.82	5.89	5.88	5.98	6.19
2396	13.52	10.38	8.96	10.17	10.56	10.57	10.12	10.26	10.23	10.37	10.81
2397	13.45	10.31	8.89	10.10	10.49	10.50	10.05	10.20	10.16	10.30	10.73
2398	7.82	4.95	4.13	4.77	5.06	5.06	4.79	4.86	4.85	4.94	5.10
2399	7.14	4.30	3.55	4.13	4.40	4.40	4.16	4.21	4.21	4.29	4.42
2400	13.77	10.61	9.16	10.40	10.80	10.81	10.35	10.50	10.46	10.60	11.05
	GR										
Average	8.53	5.62	4.73	5.44	5.75	5.74	5.46	5.53	5.52	5.61	5.81
STDEV	2.79	2.65	2.36	2.64	2.69	2.69	2.60	2.64	2.62	2.65	2.79

Straw and living mulches compared with herbicide for under-vine weed control in a Public-Private Benefit Framework

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Straw and living mulches compared with herbicide for under-vine weed control in a Public-Private Benefit Framework

Abstract

A common practice in Australian vineyards is to manage under-vine weeds with approved herbicides applied one or more times each year. A current project is testing the potentials in a range of pasture species and cereal straw as under-vine mulches compared with herbicides for weed control. Grass and legume pasture species in under-vine trials in 2015-16 have shown promising results at some sites, with grape yields in some cases exceeding those of the herbicide control plots.

Weeds compete with vines for water and nutrients and may provide a 'green bridge' between seasons, hosting pests and pathogens below the vines. Among the problems with repeated use of herbicides is the evolution of resistant populations of weeds, and their spread within the vineyard and to neighbouring properties and public lands.

This study subtracts the costs of typical herbicide regimes and those of alternative mulches and other operational vineyard costs from the values of their respective grape yields, as baseline prices and yields vary over time, to define the distribution of Gross Margins for each treatment. Further subtracting the manager's living costs, annual overheads, interest and taxes for random 10-year samples of simulated yields and prices allows estimation of long-term distributions of decadal cash balances for each under-vine treatment. Showing the probabilities of vineyard financial viability, these are private financial risk profiles for each treatment, differing by location. Juxtaposing these with the value of reduced risk of herbicide-resistant weed seed spreading beyond the vineyard permits analysis in a Public-Private Benefit Framework.

1.0 Introduction

a. This study is aimed to evaluate the economic viability of mulches as alternatives to continuous spraying of under-vine weeds. Under-vine weed control with herbicide is relatively simple, effective, inexpensive and very widely used. However, it is known that repeated use of the same herbicide over many years has the effect of selecting for herbicide-resistant genetics in the weed population.

b. 2017 holds the distinction of being the 60th anniversary of the world's first scientific documentation of herbicide resistant weeds. In 1957 a spreading dayflower (*Commelina diffusa*) growing in Hawaiian sugarcane was found to be resistant to a synthetic auxin herbicide (2,4-D). On an Ontario (Canada) roadside in the same year, wild carrot (*Daucus carota*) was confirmed resistant to the same herbicide (Collis, 2016). Since that time, 252 species of weeds have evolved resistance to 161 herbicides that span 23 of the 26 known herbicide sites of action (Heap, 2017).

c. Farmers will not "be able to spray their way out of resistance problems." While herbicides are a critical tool for large-scale weed management, it is essential "that we surround these herbicides with diverse weed control methods in order to preserve their usefulness … not sit back and wait for something better to come along." (Stanley Culpepper, quoted in Collis, 2016).

d. Resistance to "Roundup" (glyphosate) has been reported in rigid ryegrass (*Lolium rigidum*) growing with South Australian and Western Australian grapes since 1999 and 2003, respectively; as well as in South Africa (2001), France (2005) and Italy (2007) (Heap, 2017). Gains and Heap (2016) have compiled a long list of weeds with mutations that confer resistance to

glyphosate. Many annual ryegrass populations have now evolved multiple herbicide resistance across Australia (Broster and Pratley, 2006).

e. Glyphosate is the herbicide most frequently reported to induce resistance in weeds growing in combination with grapes around the world, including Sumatran fleabane (France and Greece), hairy fleabane (Australia, South Africa and the US) and horseweed (Greece & US). At least 12 other herbicide resistant weeds in association with grape production have been reported (Heap, 2017).

f. One tactic found to mitigate development of glyphosate resistance in rigid ryegrass (*Lolium rigidum)* is to follow the glyphosate application in one to two weeks with a paraquat application for a "double-knockdown" effect on the weed. The modelling results of Neve *et al*., (2003) indicated the 'double knock' tactic should indefinitely delay the onset of glyphosate resistance in *Lolium rigidum.* These two non-selective herbicides have different modes of action; glyphosate is an 'EPSP synthase inhibitor' while paraquat is a 'PSI Electron Diverter' (Heap, 2017). Weersink *et al*. (2005) noted that this 'double knock' tactic is not as effective in controlling weeds other than *Lolium rigidum*; thus, there is a need to also consider the survival of these others under a 'double knock' regime, as well as issues of phytotoxicity (harm to the crop), movement of resistant weeds to or from the farm, and risk of the 'double knock' treatment failing to prevent glyphosate resistance.

g. Presently there is evidence of *Lolium rigidum* populations exhibiting multiple resistance to both 'double knock' herbicides (glyphosate and paraquat) growing in grape crops in South Africa (2003) and Western Australia (2013). In 2009, a hairy fleabane population growing in Californian grapes was reported to have multiple resistance to the same

'double knock' combination of herbicides; in NSW (Australian) grapes, hairy fleabane resistant to paraquat was reported in 2016 (Heap, 2017).

h. The known cause of the rising incidence of herbicide resistance is the repeated exposure of weeds to herbicides. This is a recipe for the evolution of weed populations resistant to particular chemicals. What seemed to have been a magic solution may not be considered as such for long. These points highlight the need to find integrated weed management strategies to offset risks of herbicide resistance (Pratley *et al*. 1998).

i. While herbicide manufacturers have limited incentives to invest in developing the next 'silver bullet' chemical (Powles and Gains, 2016), it is most prudent for rural industries to explore other means. The present study aims to evaluate live mulch options for weed control under vines from the grower's economic viewpoint and from the perspective of public interest.

j. Where herbicide resistance has occurred in no-till broadacre farming, an attractive option for some included growing perennial pastures in multi-year phases with cropping for cost effective weed control (Doole, 2008; D'Emden *et al.,* 2008; Mojardino *et al*., 2004; Pannell *et al*. 2016). Grape-growers presently depending mainly on herbicides in no-till under-vine management may be interested in such alternatives.

2.0 Alternative means of weed management

a. A field trial aimed at finding alternative means of under-vine weed control in Iowa vineyards is illustrated by Nonnecke (2009). Mulches, in the form of straw or densely-sown grass (creeping red fescue) suppress weed growth. Both the straw mulch and herbicide treatments in Iowa were effective at conserving water, but to a fault, as they can lead to waterlogging. Eight cover crop treatments were applied for 12

consecutive years on a medium textured soil in a vineyard near Robertson, South Africa (Fourie, 2011), combining pasture legume and grass species, Tricicale and faba bean straws and herbicide and reporting on fruit yields, quality and weed control efficacy. Mixed Triticale and Faba bean straw mulches gave higher grape yields than any of the other treatments.

b. Mechanised placement of straw mulch under vines can be effective, if clean round-baled straw can be sourced economically (Grocke, 2012). Of course weed seeds can be introduced with the straw.

c. Shallow cultivation under the vines can be used to partially control weeds (Sloan, 2010; Rinieri, 2011). A disadvantage of herbicides is that soil organic matter will also diminish with the regular removal of plants other than the grape vines in a vineyard where these others enhance soil characteristics favouring the vines (Fourie *et al*., 2007).

d. In some locations it is economically feasible to integrate controlled sheep grazing as part of vineyard weed and vine management (Shannon, 2011). Because sheep would be required in the vineyard only some parts of a year, sourcing them when needed can be an issue. Damage by the sheep at some vine growth stages can limit their use for weed control (Doran, 2007).

e. Where public nuisances or environmental dis-services such as herbicide-resistant weed seeds or spray-drift may emanate from vineyards, vineyard owners could be held liable. Where ecosystem "services generated within vineyard properties are public goods, it is likely that government-generated incentives, rather than market-based payments, will be necessary as growers will have little financial interest in maintaining such services" (Tompkins *et al*., 2012).

f. Holland (2016), however, has shown that large numbers of US farmers report benefits in using some practices required for accreditation in "organic" production though they have no intention of gaining organic certification due to the additional, restrictive and costly requirements for certification and the lack of secure rewards in terms of price premiums.

g. In regions where mulches can be demonstrated to clearly offer better options from the grape-grower's economic viewpoint, we should expect early adoption without any other incentives. This paper should help identify and clarify the incentives influencing grape-growers with regard to their costs and benefits of adoption, as well as the associated public costs and benefits. The definition of environmental and other conditions that favour particular weed-control options will be clarified with the additional observations possible with ongoing field trials and laboratory work.

3.0 This study has three aims:

a. The first aim is to qualify the public consequences of switching from herbicide to mulch-controls for under-vine weeds. With careful use of a herbicide such as "Roundup", by alternating its use with non-chemical controls such as mowing, cultivation and grazing, the rate of evolution of herbicide resistance will be reduced. However, multiple sprays year after year can result in rapid selection in favour of herbicide-resistant weed populations. Spray-drift damage to vines or vegetation on neighbouring properties may occur accidently. The extent of potential damages will depend on the nature and sensitivity to such risks on neighbouring private and public lands and water. Spread of resistant weed seed outside the vineyard can be expected when resistance appears in vineyard weeds. Weed seeds travel on the wind, in runoff water, on the wheels of vehicles, on the feet of people and sheep. There are also major OH&S concerns

with some herbicides, such as paraquat. These in most cases are kept well in hand as label-directions and other regulatory controls are observed by farmers.

b. With the limited results we have from the trials so far, and information on longer-run weather and price variations, **the second aim** is to compare distributions of vineyard profitability specific to key grape production regions and varieties using the two methods of weed management. The private consequences of keeping the current practice of using herbicides for under-vine weed control or switch to a 'mulching' approach will depend on differences in vineyard cost, effects on vineyard fruit yield and quality and efficacy in weed control. These costs and benefits may vary with weather and prices from year to year. Further, some customers insist on organic products grown without modern technologies such as herbicides or chemical fertilisers, often raising the costs of production. Freedom from herbicide is key to certified organic production. Therefore, weed control in the under-vine area is a major challenge to growers wishing to embark on organic production systems.

c. **The third aim** is to juxtapose private benefits and costs with public benefits and costs of the options. Mentioned earlier is the need for care in herbicide applications to avoid spray drift to the neighbour's crops or to public lands. The 'win-win' result desired (and expected for some locations) is for positive net private and net public benefits from change. In the marketplace, premiums are often paid for products guaranteed to be 'clean and green'. Particularly important to the positive image of Australian agricultural exports is to maintain the verifiable reality of the claim of safety and wholesomeness.

4.0 Materials and methods

a. Economic consequences of changing weed management in a private vineyard will depend on the cost elements of the changes and the biological responses affecting crop yields and quality. Weather and product price variations also affect the outcomes. Field trial results are available for one year from two contrasting South Australian districts (Barossa Valley and Langhorne Creek). These are in established vineyards, each growing the predominant grape variety for their districts (Shiraz and Cabernet Sauvignon, respectively). The trials, first sown under vines in 2014, were unsuccessful due to dry conditions and poor seed set. They showed no grape yield differences and had to be re-sown in 2015 for the grape harvest in 2016 to provide our initial basis for calculating baseline estimates of (grape) yields under the different treatments.

b. Variety-specific weighted average prices and yield levels for the harvests in each season over the 2006-2016 period were found for each of the two districts in the '*2016 South Australian Winegrape Crush Survey*' (SAWCS) published by Wine Australia (2016). This allowed historical ranges of district-specific yield x price variations for combination with fixed and variable costs to estimate distributions of economic outcomes. We adopt the method developed by Hutchings (2013) and exemplified in Hutchings *et al*. (2016) and Nordblom *et al*. (2016) for practical calculation of farm financial risk profiles.

c. We combine the economic results with information on public benefits and costs in a Public-Private Benefit Framework, following Pannell (2008). An example of the basic logic of this form of presentation of policy choices is

given in Nordblom *et al.* (2015). Also see Pannell (2017) for many further examples.

5.0 Data

a. For the moment, our measure of public benefits and costs is qualitative, and considers both ceasing or reducing regular use of herbicide spray regimes under the vines or continuing dependence on them as usual. It also considers reduced threats to neighbouring properties from the spread of seed of herbicide-resistant weeds and from spray-drift of herbicides.

b. Wine Australia's 'South Australian Wine Crush Survey' (SAWCS, 2016) provides a rich source of information on district and variety-specific prices and yields from past years. We use price and yield data only from the 2006 – 2016 period. Visual estimates of prices were taken for Barossa Shiraz grapes from the 2016 SAWCS chart on page 34, and for Langhorne Creek Cabernet Sauvigon (Lang Ck Cab Sav) grapes from the chart on page 62. The price data obtained this way were already expressed in terms of dollars per tonne ($/t). The same charts presented grape production in terms of district totals harvested (or crushed) each season. These summed to 54 and 60 thousand tonnes (kt) in 2016 for all grapes in the Barossa and Langhorne Creek districts respectively.

c. The Shiraz grapes comprised about 60% of the Barossa district harvest, or 32.5 kt of a total 54.4 kt of all varieties together (2016 SAWCS, pp 33-34). Cabernet Sauvignon grapes accounted for about 30%, or 18.3 kt of Langhorne Creek's total 60.1 kt harvest (2016 SAWCS, p 61). These proportions of the focus varieties were applied to the annual total harvests in the previous years divided by their 2016 vineyard areas in the two

districts (6,869 hectares (ha) and 1,879 ha, respectively) to estimate yields in tonnes per hectare (t/ha), from pages 35 and 63 (2016 SAWCS) for Barossa and Langhorne Creek districts.

d. The above results are sufficient to capture ranges and correlations among yield and price variations over the most recent 11-year period to illustrate the form of analysis that is used in our risk analysis. We take the historical yield series to represent the baseline cases of production, which employ multiple herbicide sprays each year for under-vine weed control. See **Table 1** and **Figure 1** for the historical series of prices and yields, which are the basis for generating prices and yields for 240 seasons (**Figure 2**) that were stochastically simulated to exhibit the same statistical characteristics (means, standard deviations and correlations). The Gross Revenues (price x yields) simulated for the two locations (in $ thousands /ha) as shown in **Figure 2c** are plotted as probability distributions in **Figure 3**, which indicate median Gross Revenues of about $7,500/ha in both locations.

e. The field trial of alternatives to repeated herbicide applications were set up in four replicated random blocks in a semi-commercial Shiraz vineyard in the South Australian Barossa district and a commercial Cabernet Sauvignon vineyard in the Langhorne Creek district. The control treatment in 2015 was the continued use of herbicides, **(Option 1).** Alternative mulch treatments in the trial included a sown cocksfoot perennial grass (*Dactylis glomerata*, cv Kasbah) **(Option 2)**; a sown annual ryegrass mixed with annual Burr-Medic (*Medicago polymorpha*) **(Option 3);** and a Triticale straw mulch **(Option 4)**.

f. As of this writing we have the grape harvest yields only for 2016 from the replicated plots at the two locations. As is common, yields from measured

plots were greater than averages of commercial vineyard yields in 2016 mentioned in **Table 1**; therefore, in **Table 2** we use the trial plot yields of the alternative treatments relative to the herbicide control plots as yield indices for adjusting respective district-level (t/ha) yields in our risk analyses. For the moment, we assume similar proportionate yield effects across seasons with poor and good growing conditions. Further, we assume fruit quality is constant across all treatments at a location in a given season and price per ton is the district average price in that season. Current laboratory tests and future trial harvests will provide the bases for greater confidence in appropriately adjusting these initial assumptions.

g. For the present study we used the 11-year sequences of prices and yields (**Table 1**) to generate a longer, 240-season sequence. These simulated seasons were generated in a process using the vector of means (i.e., for P1, P2, Y1, Y2 in Table 1) and a variance-covariance matrix, which was derived from the standard deviations and correlation matrix in Table 1 for our 11-year history of grape prices and yields. A 'Cholesky Decomposition' routine can be used to simulate multivariate series of jointly distributed random yield and price variates that share the statistical characteristics of the original data set (Nordblom, 1987, pp 66-69). Dr John D. Finlayson used the more stable **'eigen decomposition'** of the variance-covariance matrix, as explained in his technical footnote (below)[1], to generate the 240 sets of stochastic price and yield variates illustrated in **Figure 2a** and **b**. This

[1] We wanted to draw samples from a specified multivariate normal distribution. Our approach was to combine MonteCarlo techniques with an eigen decomposition of the variance-covariance matrix of selected data. The statistical package R provides a convenient platform to perform these calculations. Specifically: we used the function 'mvrnorm' from the library MASS (see https://cran.rproject.org/web/packages/MASS/MASS.pdf).

captures information from the 11-year historical series beyond their averages and standard deviations, allowing a more complete and balanced analysis of the prospects for the different options. The historical series (Table 1) are neither independent nor wholly random. For example, the reported fruit yields for the two districts in the historic series are strongly positively correlated (**r=0.68**); as they are less than 100 km apart they tend to face high-rainfall years and drought years together. Because they face similar global markets, their prices are also positively correlated (**r=0.33**). The Barossa Shiraz grape harvest yields and prices were negatively correlated (**r=-0.53**), as expected for many agricultural commodities. Unexpectedly, the Langhorne Creek prices and yields were positively correlated (**r=0.35**); this positive correlation is also reflected in our 240-season simulation sequence (Table1 and Figure 2).

h. Ranking each of the Gross Revenue arrays behind **Figure 2c**, from their lowest to highest values allows plotting them as cumulative distribution functions (**Figure 3**). Because the Barossa fruit yields were lower, and prices higher than those of Langhorne Creek in our analysis, their median Gross Revenues (price x yields) were nearly the same, at about $7,500/ha. This is a coincidence that helps us illustrate the importance of costs in determining the likelihoods of business profitability and survival.

i. To calculate Gross Margins per hectare, starting with the Gross Revenues ($/ha) we subtract Operational Costs per hectare (**Table 3**), comprised of fixed and variable elements. Fixed annual costs are for requirements that do not vary with grape yields. Also subtracted from gross revenues are the variable costs; those <u>that do vary</u> with yields, including extra harvesting costs, extra harvest labour, transport costs, and levies, calculated as $/t. These operational costs are quantified in Table 3 with

approximate values (based on an anonymous 2016 budget from Griffith, NSW), which in reality, must differ from vineyard to vineyard.

6.0 Analysis

a. Gross Margins (before manager's living expenses, overheads, interest and taxes) were calculated by subtracting the appropriate Operational Costs ($/ha in Table 3) from both Barossa and Langhorne Creek Gross Revenues (**Figure 2c**) for each of the 240 simulated price and yield seasons in the two districts, as illustrated in **Figure 4**. Notice that in each season both the Gross Revenue and Operational Costs vary with fruit yield (t/ha), adjusted relative to the HERBICIDE treatment according to the under-vine treatment option indices in **Table 2**. As Gross Revenue also varies with fruit price ($/t), Gross Margins vary each season with both price and yield of that season. Our Operational Cost assumptions for the items comprising fixed and variable costs each season have some elements specific to each of the four under-vine weed management options, with the HERBICIDE treatment taken to have the lowest cost. Thus, in each simulated season, we have the following expression:

Gross Margin = Gross Revenue – Operational Costs (fixed and variable)

In this equation, only the fixed costs are assumed to hold constant while the remaining terms will vary from season to season as grape prices and yields change.

b. Four arrays of 240 annual Gross Margin values, representing the four under-vine options, were produced for each of the two districts. Each of the 240 rows in the combined eight arrays are considered to have equal probability.

c. Curves indicating the probability distributions of annual Gross Margin values per hectare below specific amounts are presented in **Figure 4** for each of the four under-vine options for each district. Gross Margin values are on the horizontal axes and cumulative probabilities on the vertical.

d. If our assumptions on costs, prices, yields are correct, and the results of a single season's field trials are adjusted for better and worse seasons, the Gross Margin curves for the HERBICIDE Option 1 in both districts are slightly exceeded or matched by both Option 3 (BURR MEDIC) and Option 4 (TRITICALE STRAW mulch). In the Barossa district the straw mulch slightly beats Option 3. In Langhorne Creek, this ranking is reversed. However, the differences among Options 1, 3 and 4 appear insignificant. The large shortfalls in Gross Margins associated with COCKSFOOT perennial grass, Option 2, are due chiefly to the lower fruit yields measured in the field trials (Table 2) and projected here to hold in relative terms across the varying seasons in both districts. In the case of Langhorne Creek the indication is that Option 2 could lead to negative Gross Margins five years in ten; and less than 2 years in ten in the Barossa vineyard. Whether this initial perspective is valid should be clarified with future harvests and laboratory research.

e. Most pronounced are the large differences between the districts in Gross Margins per hectare due to the higher costs in Langhorne Creek. These are associated with higher annual fixed costs assumed for water and other inputs supporting that district's greater average productivity (Table 3), and consistent with this, higher annual variable costs at harvest, than in the Barossa area.

f. The indication in **Figure 4**, representing a Shiraz vineyard in the Barossa district, with Option 1 (HERBICIDE) outcomes, is for the probability of positive Gross Margins greater than 93%, with a median probability of reaching $2,300/ha and a 20% chance of exceeding $4,000/ha. Of course these probability estimates will change with different input costs.

g. The Cabernet Sauvignon vineyard in Langhorne Creek (Figure 4) with Option 1 (HERBICIDE) may encounter negative Gross Margins with 20% probability. Its median Gross Margin is about $1,900/ha and there is a 20% chance of exceeding $3,300/ha. The same caveat regarding the effect of different input costs applies in this district as well as the other.

h. Farm financial risk profiles that show the long-term probabilities of farm business profits and losses were approached in two additional steps. First, samples of ten-season length were drawn randomly from our 240-season series of Gross Margins for the 8 under-vine options across both districts. Assuming a vineyard area of 50ha for each such ten-season sample, we subtracted an assumed manager's annual living allowance (drawings) of $80K, annual overhead payments of another $80K, then subtracting accumulating interest and taxes year by year to calculate a decadal ending cash flow balance. See **Figure 5** for three examples of such sample decades in the Barossa case with decadal results for each of the treatments. In a good decade (209) of weather and prices the farm may produce profits of $1.5M. In a poor decade of weather and prices (55) farm losses may exceed -$1.0M. Within the 240-season sequence of Gross Margins are 231 unique decades in the random draw process.

i. Many random draws of decades from the Barossa and Langhorne Creek Gross Margin series were made for the Decadal cash flow calculations for each under-vine option. The smooth distributions of the resulting decadal

cash flow balances define **Long-Run Farm Financial Risk Profiles**. We considered results with annual overhead costs of $80K and $120K separately for each district to demonstrate the effects on profitability. See **Figure 6** for the Barossa results. After subtracting from annual Gross Margins the manager's living expenses, and annual overhead payments, interest and taxes for each decade and each under-vine option we define points on their longer-term distributions. Notice the COCKSFOOT option has less than a 20% chance of profits and greater than 80% chance of losses over a random decade with $80K annual overheads. The HERBICIDE treatment has better than 85% chance of profits, while the BURR MEDIC and STRAW mulches indicate better than 94% chances of profits. The latter shows only a 5% chance of maximum decadal cash flow balance of $2M.

j. All Barossa risk profiles shift far down in decadal cash margins with an increase in annual overhead costs from $80K to $120K. Only the best options exhibit greater than 30% chances of long-term profits (Figure 6).

k. Long-run Farm Financial Risk Profiles for Langhorne Creek are given in **Figure 7**. Assuming $80K in annual overheads, the HERBICIDE under-vine treatment would be profitable with just over 40% probability. In contrast the BURR MEDIC option appears profitable with about 60% probability. Increasing annual overhead costs to $120K would leave the BURR MEDIC option with only 25% probability of profitability.

l. In order to put the farm risk profiles in more familiar terms, as probabilities of average annual cash flow balances, these are assembled in **Table 4** for all under-vine treatments for both districts and with both annual overhead levels.

7.0 Discussion

a. The field trial results are provocative in suggesting there may be yield-improving benefits from some mulch treatments, and yield-reducing effects of one. When joined with economic information, interest in continuing the field and laboratory research in this area is considerable. While our initial results are encouraging there are several important questions requiring answers. Among these is the need to gain a fuller understanding of the efficacy of the under-vine management options in suppressing weeds together with appreciation of how to maintain that efficacy over subsequent seasons.

b. In order to understand the biological interactions affecting grape yields and quality in the various under-vine weed management options, soil microbial populations have also been monitored in the plots with sampling and DNA analysis. Differences were found in soil microbial populations among the under-vine mulch plots and herbicide-only plots. It is hypothesised that these different microbial populations are instrumental and even key in vine productivity and fruit quality. Allelopathic (antagonistic) relations are found among some species of plants, microbes and invertebrates, and symbiotic (beneficial) relations are found among others. It is too early to say with confidence that a lower-yielding treatment compensates with better quality fruit, though this could be an a priori hypothesis. These processes need to be better understood and are part of the larger study.

c. Weeds compete with vines for water and nutrients and may provide a 'green bridge', hosting pests and pathogens between seasons below the vines. Going forward, there is a need to ensure that such undesirable

characteristics are not exhibited by mulch options meant to take the place of weeds.

d. Where herbicide resistance is not (yet) in evidence locally, the rise of herbicide resistance around the world implies the prudent course is to explore such options.

e. If there are private economic benefits from integrated weed management using different control measures over time to maintain the efficacy of herbicides, most of these benefits will go to vineyard owners, justifying research levies they pay.

f. Specific recommendations on plant species giving the best results from under-vine mulching are likely to differ among districts as weed populations, soils, climates, input costs and output prices differ. Weed suppression is a key.

g. At stake in the world marketplace is the fact that premiums are often paid for products guaranteed to be 'clean and green'. It is particularly important to the image of Australian agricultural exports to maintain the verifiable reality of the claim of taste, safety and wholesomeness.

8.0 Conclusions

a. There is no reason to expect the recent 11 years of weather and prices to persist in the future. Different future price and yield scenarios can be explored to examine the changes in vineyard economic outcomes. Implicit in our results is the expectation of no differences in grape quality among the under-vine treatments for a certain variety. If there are found to be systematic quality differences that affect grape values per tonne, these must be taken into account. Another improvement in our analysis will come with field trial results in further seasons to escape our simple assumption of

yield indices relative to yields of the herbicide treatment in one season holding over past seasons. We should expect somewhat different relative yields between seasons.

b. It is reasonable to expect a continued rise in herbicide resistance in vineyard weeds, so it is prudent to search for more sustainable alternatives, such as mulches. Considerably reduced use of herbicides will be required in many cases in order to preserve their usefulness and efficacy. We may expect that some mulch options will be more effective and efficient than others in making reduced herbicide use easier and more economically attainable than in the past. The private economic benefits of integrated weed management, using different control measures over time, to maintain the usefulness of herbicides, will largely be reaped by grape-growers over time, justifying the research levies they pay. Where herbicide resistance is not (yet) in evidence, the rise of herbicide resistance implies the prudent course is to explore such options.

c. Specific recommendations on plant species giving the best results from under-vine mulching are likely to differ among districts with yield and quality differences, as weed populations, soils, climates, input costs and output prices differ.

d. At stake in the world marketplace is the fact that premiums are often paid for products guaranteed to be 'clean and green'. It is particularly important to the image of Australian agricultural exports to maintain the verifiable reality of the claim of taste, safety and wholesomeness. Public Good claims for the present research project can include reduced herbicide use to sustain its usefulness in integrated weed management, improved ecosystem service from the soil in terms of fruit quality and/or yield,

reflecting positively on the region as well as from its and reduced diesel use and CO_2 emissions from multiple herbicide applications.

e. The present research project has made a start with some provocative results showing some under-vine treatments (Triticale straw and Burr medic) associated with better fruit yields than the herbicide treatment. A single year's trial results form part of the larger picture, which must be tested further for reliability and efficacy. If their costs are not much higher than we have assumed **and** fruit quality is not reduced, **and** weeds are controlled, then such treatments could readily find roles in integrated weed management. This would describe the '**Good result'** in Figure 8, where the private grape-growers and both the local and wider publics feel the benefits, vindicating the research effort. The '**Dream result**' in Figure 8 is hoped for, of course, but not required to justify this research.

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Table 1. Selected historic series of prices and yields, 2006-16*, and the comparable statistical characteristics of a simulated series of correlated random variables for risk analysis that mimics the historical sequence.

	P1	P2	Y1	Y2
	Barossa Shiraz price ($K/t)	Lang Ck Cab Sav price ($K/t)	Barossa Shiraz yield (t/ha)	Lang Ck Cab Sav yield (t/ha)
2006	1.16	0.85	6.96	11.07
2007	1.51	0.92	3.48	6.57
2008	1.74	0.99	5.84	9.94
2009	1.51	0.82	4.48	7.52
2010	1.34	0.66	5.30	7.52
2011	1.19	0.58	5.54	6.40
2012	1.51	0.77	4.54	7.87
2013	1.72	0.89	3.77	7.61
2014	1.83	0.77	3.83	7.87
2015	2.13	0.84	3.89	6.31
2016	2.20	0.78	4.77	9.86

	Statistical characteristics of simulated series (n=240) **			
	P1	**P2**	**Y1**	**Y2**
Means	1.638	0.813	4.711	8.101
STDEV	0.356	0.118	1.104	1.595
Correlations:				
P1	**1**	0.285	-0.514	0.003
P2		**1**	-0.209	0.276
Y1			**1**	0.690
Y2				**1**

*** Source:** Wine Australia (2016). *2016 South Australian Winegrape Crush Survey*.

****** Simulation based on the above historical series by John Finlayson

Table 2. 2016 yield indices of alternative mulches relative to herbicide controls at two locations, Barossa and Langhorne Creek. **Source:** authors

	no mulch	**---sown living mulches ---**		**applied mulch**
Treatment:	**HERBICIDE** control	Perennial **COCKSFOOT** grass	Ryegrass mixed with **BURR MEDIC**	Triticale **STRAW** mulch
Field trial location				
Barossa yield index	**1**	**0.881**	**1.033**	**1.104**
Plot yield (t/ha)	8.82	7.77	9.11	9.74
Langhorne Creek yield index	**1**	**0.754**	**1.083**	**1.092**
Plot yield (t/ha)	19.95	15.05	21.61	21.79

Table 3. Annual Vineyard Operational Costs, fixed and variable, by location*

COST CATEGORIES:	ANNUAL FIXED COSTS		VARIABLE COSTS	
	Barossa Shiraz fixed costs ($/ha)	Lang Ck Cab Sav fixed costs ($/ha)	Barossa Shiraz variable costs ($/t/ha)	Lang Ck Cab Sav variable costs ($/t/ha)
Undervine weed control Options				
1. Under-vine herbicide sprays	75	80		
Living mulch estabished & maitained				
2. COCKSFOOT perennial grass	150	150		
3. Ryegrass & BURR MEDIC	120	120		
Straw mulch purchase & apply				
4. TRITICALE STRAW mulch	600	600		
OTHER COSTS				
Other spray application costs	300	400		
Cultivation, sowing for inter-row veg	200	200		
Slasher-mulcher for inter-row veg	250	250		
Pruning	300	300		
Fertilisers				
Spreadable	300	300		
Foliar	70	70		
In drip irrigation water	75	75		
Insecticides	35	35		
Fungicides	260	260		
Vineyard repairs and maintenance	400	400		
Electricity for pumping	150	250		
Irrigation water	150	300		
Land/lease payments	500	500		
Crop Insurance (4% of gross returns)	301	296		
Harvesting	300	300	+ 30	30
Freight			15	15
Levies			10	10
Labour/wage ($25/hr, 40 hrs/ha) + (2 hrs/t)	1,000	1,000	+ 50	50
Fixed annual costs except under-vine ($/ha)	**4,591**	**4,936**		
Variable costs, depend on fruit yield ($/t)			**105**	**105**

*** Source:** except for mulch costs, this table is based on an anonymous 2016 budget from Griffith, NSW, with adjustments by the corresponding author to reflect yield differences

Table 4. 10%, 50% and 90% probabilities for average annual cash balances less than or equal to calculated dollar amounts after interest, taxes, drawings and $80K or $120K in annual overhead costs with four under-vine treatments in Barossa and Langhorne Creek vineyards of 50ha. **Source:** authors

BAROSSA

	$80K overhead			
Probability	HERBICIDE	COCKSFOOT	BURR MEDIC	STRAW
10%	-$4,200	-$62,169	$8,777	$7,907
50%	$52,293	-$26,001	$76,020	$78,761
90%	$140,081	$12,665	$173,928	$183,324

	$120K overhead			
Probability	HERBICIDE	COCKSFOOT	BURR MEDIC	STRAW
10%	-$67,710	-$128,505	-$55,579	-$57,014
50%	-$27,678	-$92,120	-$15,270	-$13,065
90%	$18,439	-$56,374	$45,828	$54,074

LANGHORNE CREEK

	$80K overhead			
Probability	HERBICIDE	COCKSFOOT	BURR MEDIC	STRAW
10%	-$126,437	-$221,304	-$99,001	-$130,206
50%	-$7,922	-$131,526	$33,353	-$340
90%	$104,719	-$73,882	$185,933	$132,203

	$120 overhead			
Probability	HERBICIDE	COCKSFOOT	BURR MEDIC	STRAW
10%	-$193,285	-$288,151	-$165,848	-$197,053
50%	-$74,364	-$198,165	-$37,314	-$67,267
90%	$2,095	-$140,664	$68,629	$14,562

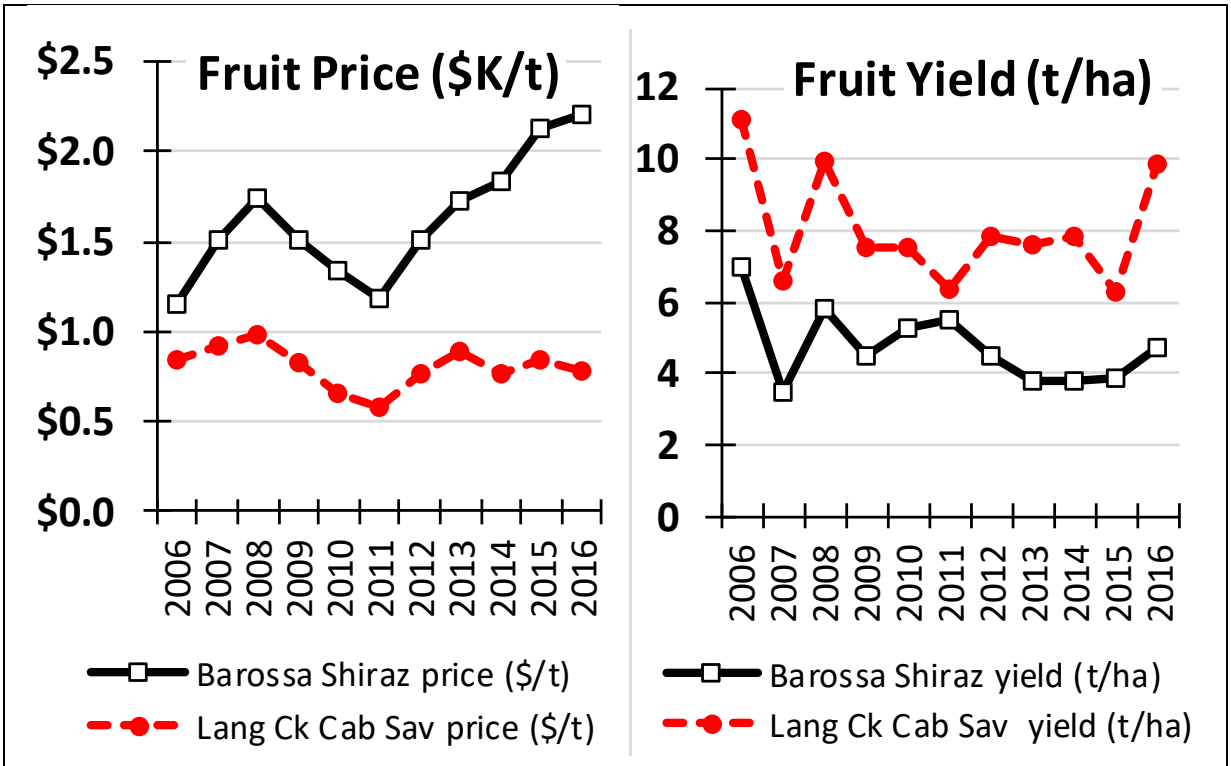


Figure 1. Reported fruit and price yields (2006-2016) for Shiraz grapes in the Barossa Valley and Cabernet Sauvignon grapes in the Langhorne Creek district.
Source: Wine Australia (2016) *South Australia Winegrape Crush Survey.*

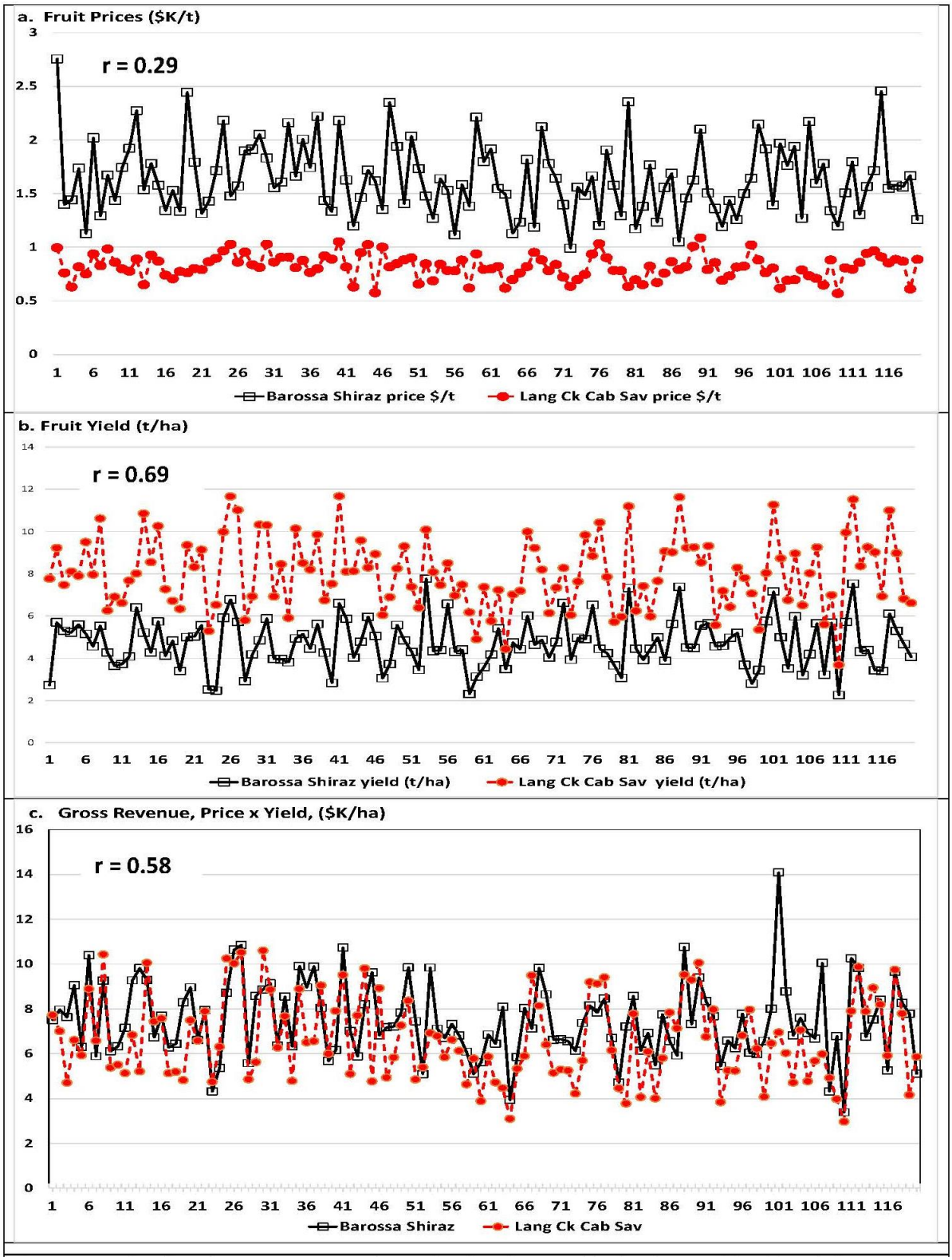


Figure 2. Simulated stochastic time series with correlated jointly-distributed random values for **a)** prices, **b)** yields and **c)** gross revenues of two variety / district combinations for 120 of 240 seasons with statistical properties modelled on 2006-2016. **Source:** derived from values in Table 1 by authors

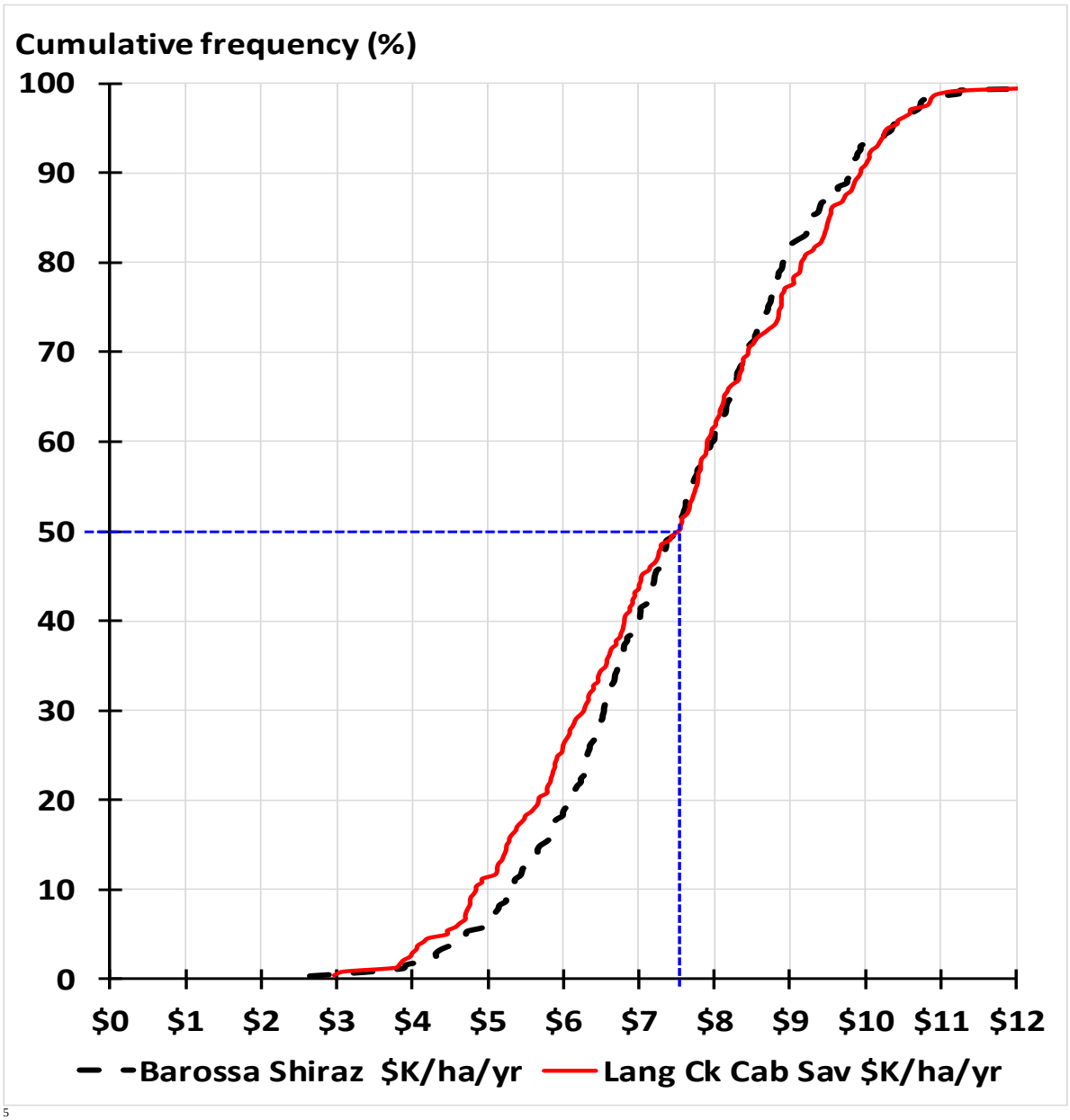


Figure 3. Annual gross revenues (price x yield) plotted as cumulative distribution functions based on simulated values as in Figure 2c.

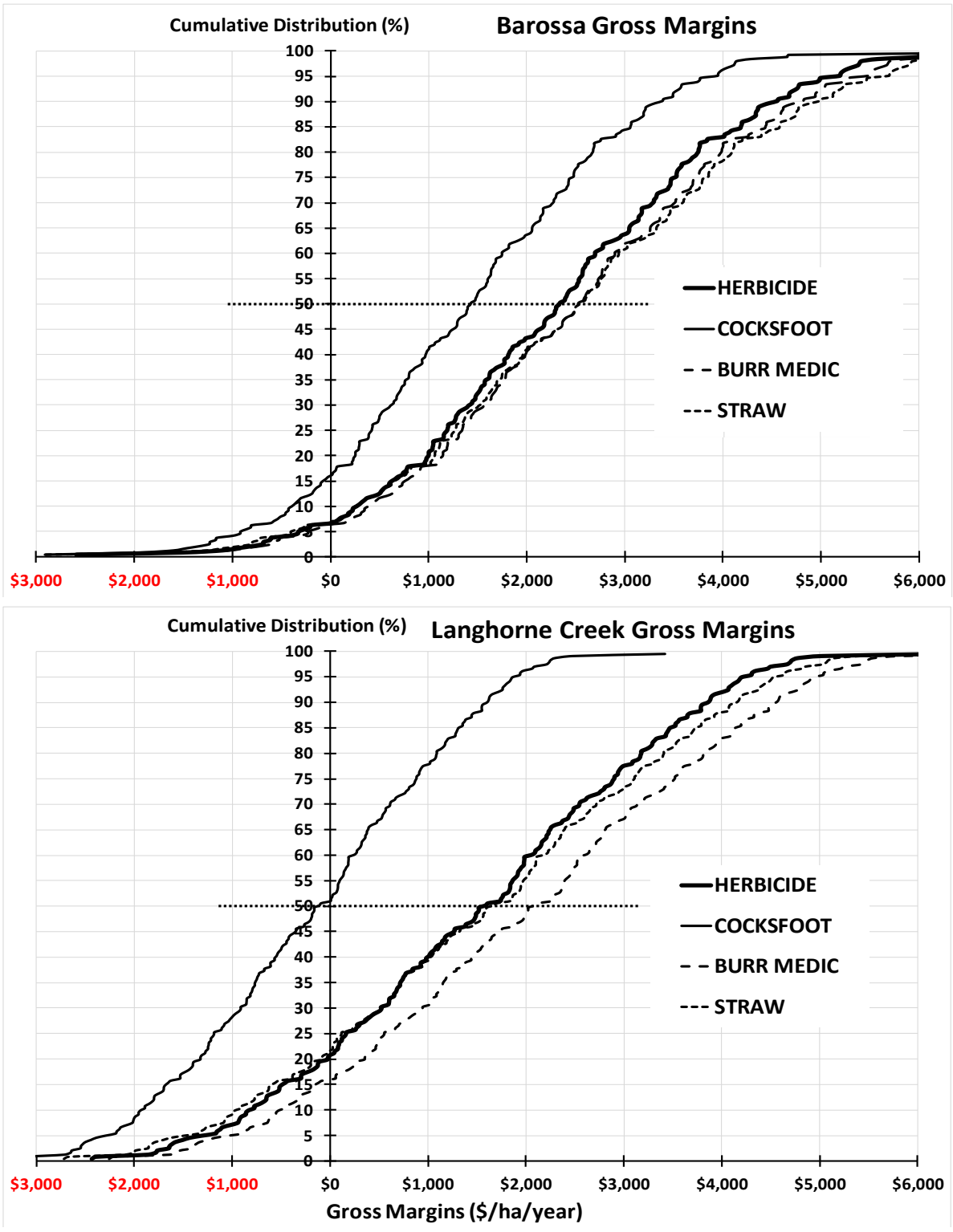


Figure 4. Cumulative distributions of Gross Margins: simulated as Gross Revenues minus Operational Costs ($/ha), before living costs, overheads, interest and taxes, of four under-vine treatments at experimental sites in two South Australian wine districts. **Source:** compiled by authors

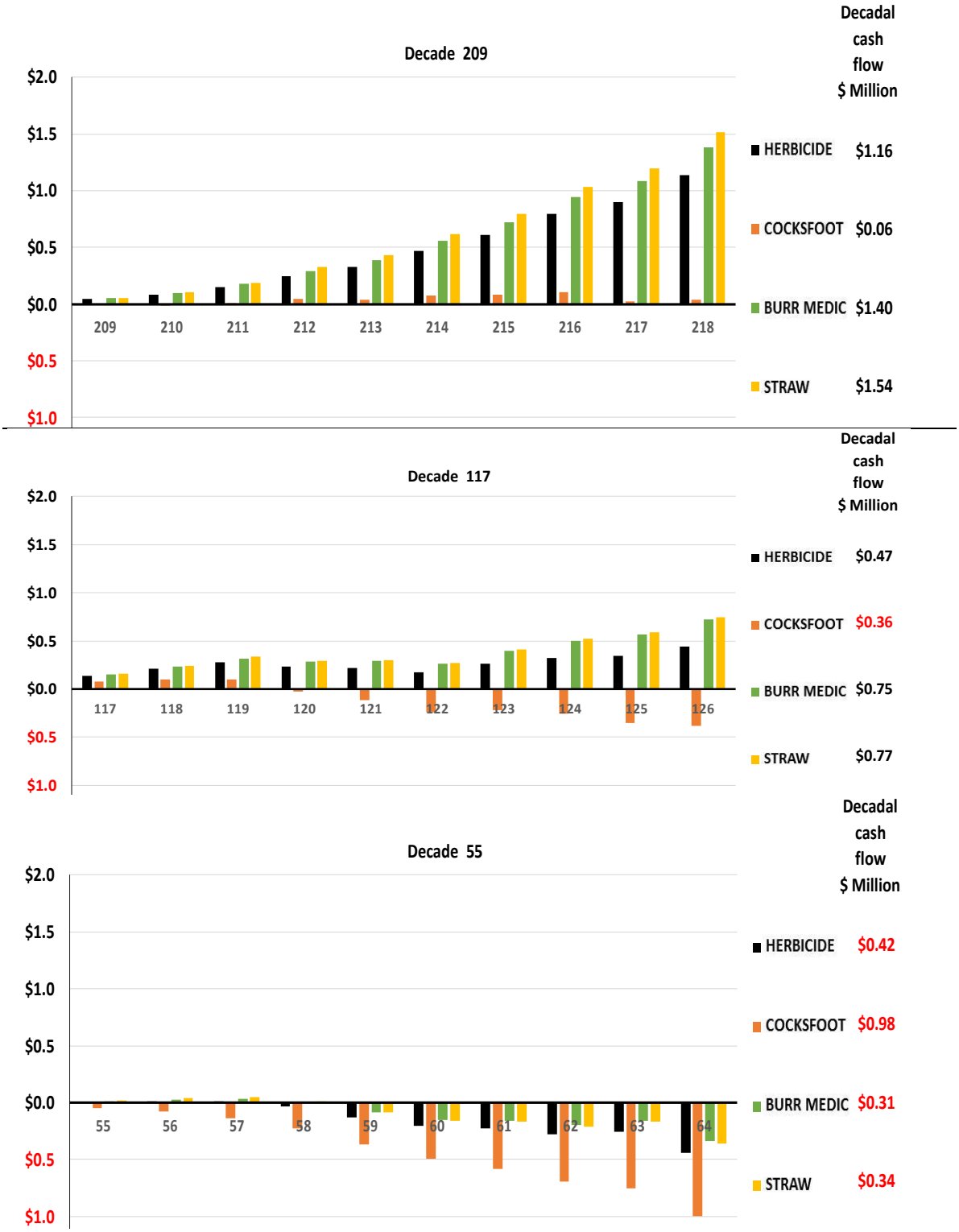
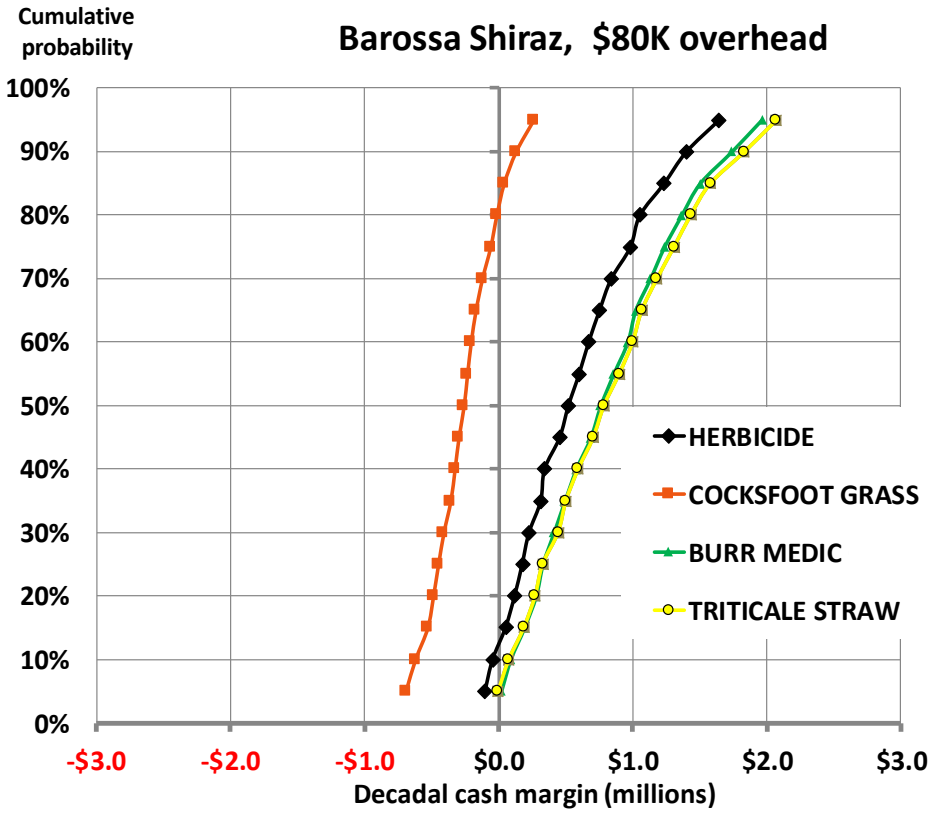


Figure 5. Examples of the annual and decadal cashflows (in $Millions) for a 50 ha Barossa vineyard with four under-vine treatments over three random decades (209, 117 and 55) among 231 stochastically simulated decades of varying fruit yields and prices, given $80K annual overhead costs. **Source:** compiled by authors



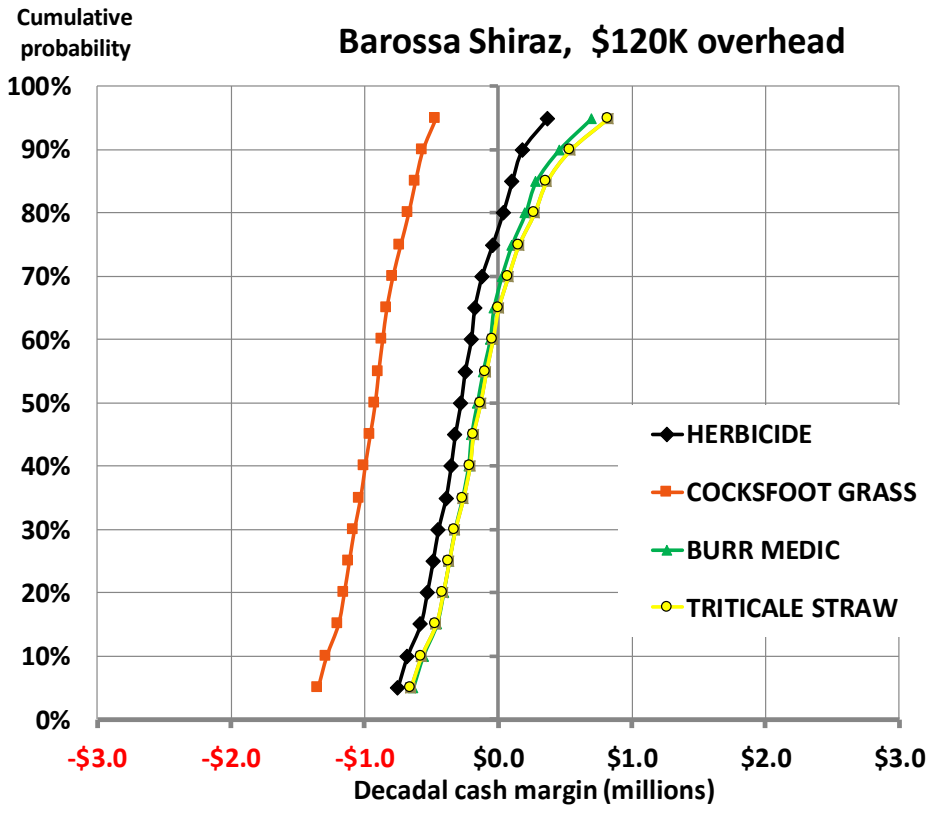


Figure 6. Cumulative distribution functions of decadal cash balance with four under-vine treatments on a 50 ha Barossa vineyard after interest, taxes, drawings and $80K and $120K annual overhead costs. **Source:** authors

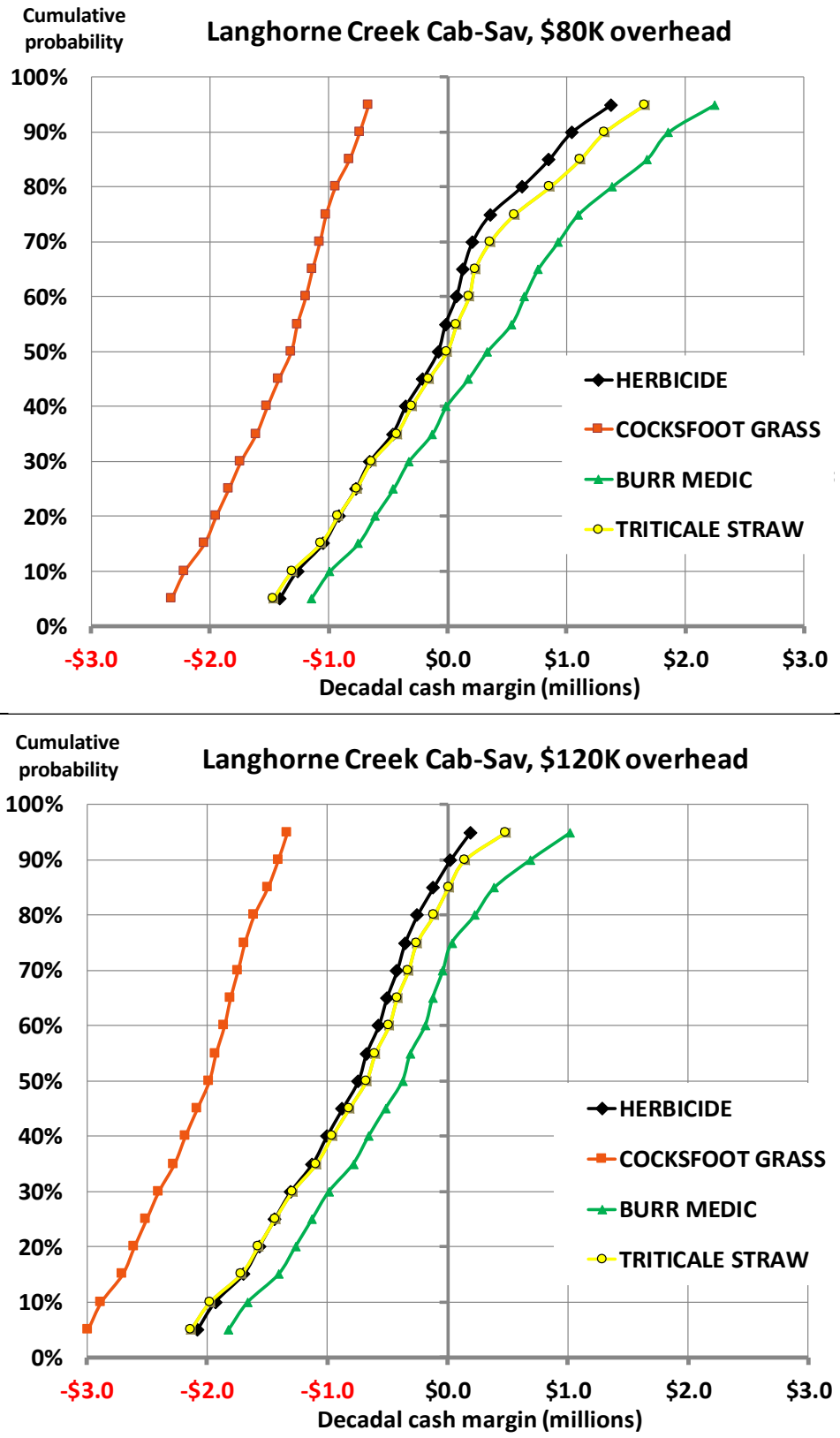


Figure 7. Cumulative distribution functions of decadal cash balance with four under-vine treatments in a 50 ha Langhorne Creek vineyard after interest, taxes, drawings and $80K and $120K annual overhead costs. **Source:** authors

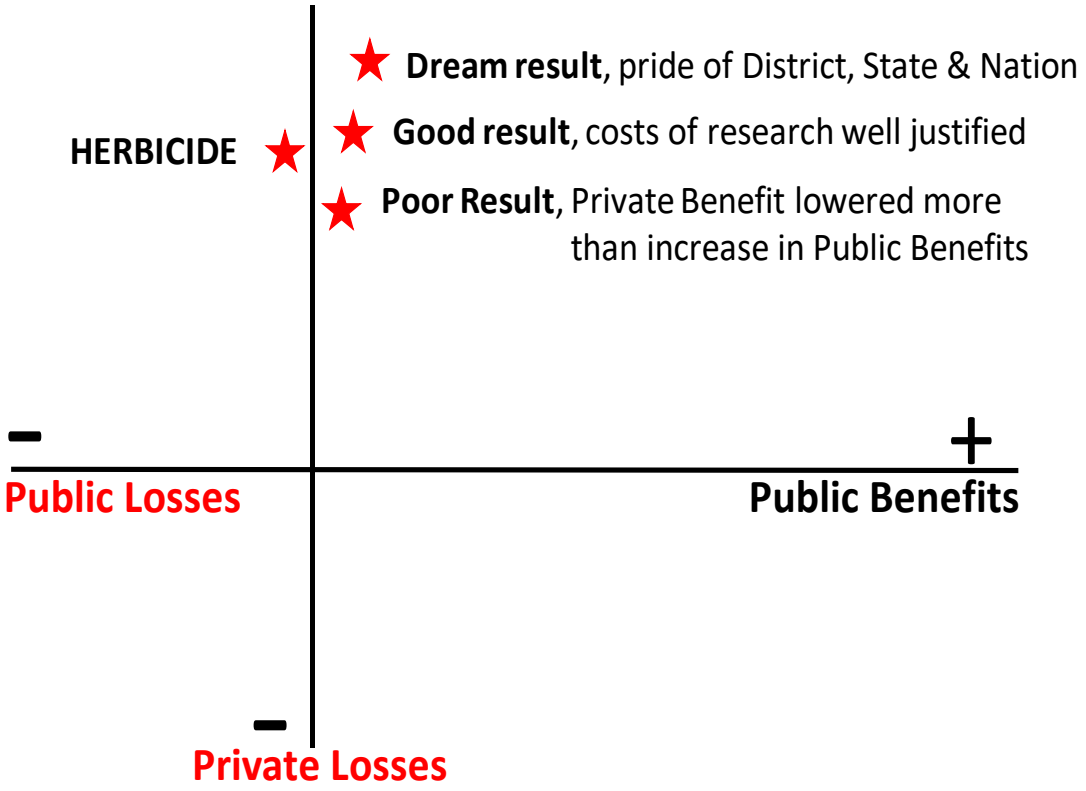


Figure 8. Research results in a public-private benefit framework (stylised). Presently, herbicides have important roles in vineyard weed management, being low-cost, easy to use and reliable. The rapid rise of herbicide resistance in weeds is a challenge to that reliability that will require integrating other means of weed management in vineyards as surely as it has in Australian broadacre agriculture. **Source:** authors