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Financial comparisons of under-vine management systems in four South Australian vineyard districts*

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Conventional viticultural practice in Australia and elsewhere involves removal of under-vine vegetation using herbicides or cultivation. Concerns over the long-term effects of herbicides on soil health, evolution of resistant weeds and possible impacts on human health motivate the search for alternative weed management options. Industry-supported trials on commercial vineyards in four South Australian regions investigated standard practices of straw mulch and bare earth created with herbicides, compared to under-vine cover crops, focusing on soil health attributes (soil carbon, soil microbiological processes, etc.) and grape yields in 2016 and 2017. Measured yields with the Control (herbicide) treatment were combined with published district grape prices and yields over the 12-year (2006–2017) period, defining multivariate distributions of gross revenues ($/ha). Assuming all treatments produce grapes of equal quality and price as the Control, our results showed median per-hectare gross margins greater than the Control in the Barossa district, lower than Control in Riverland, and mixed results in Langhorne Creek and Eden Valley. Multi-year risk profiles, based on decadal whole-farm (50 ha) cash flows for each treatment, were calculated using Monte Carlo analysis, based on historical yield and price

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distributions. These risk profiles showed the under-vine treatments may result in major differences in long-term vineyard financial viability.

Key words: decadal cash margin, farm financial risk, risk profile, under-vine treatments, wine-grape production.

1. Introduction

Weeds are often described as 'a plant growing out of place', and in the vineyard context this has generally defined all plants growing in the under-vine zone. To prevent weeds removing soil moisture that might otherwise be available to the vines, herbicides, and to a lesser degree cultivation or mulching with thick layers of cereal straw or coarse compost, have been employed. Herbicides are comparatively cheap and easy to apply and for many years have defined the image of vineyards, where managed plants are allowed to grow between the vine rows and the zone under the vines is kept bare following repeated applications throughout the year.

While this practice has been effective in achieving the weed free goal, there is a legacy that now requires a change in management practices. Under-vine soil carbon, which is the energy source for the soil micro and macro organisms, has declined due to the lack of plants growing under-vine (Whitelaw-Weckert *et al.* 2007; Rawnsley 2014; White and Kristic, 2019). This has caused soil structural degradation, which reduces the rate of water infiltration and suppresses root growth through high soil strength (Lanyon *et al.* 2004). The soil microbial community is diminished with reduced access to labile carbon (Whitelaw-Weckert *et al.* 2007).

Aside from a decline in soil health following years of repeated herbicide application, there are now populations of weeds that are resistant to glyphosate, the most commonly used knockdown herbicide, making their control increasingly expensive with other products. Concern regarding worker safety for all the major knockdown herbicides is now causing a review of practices by many operators. Market access has the potential to be compromised as the EU again assesses the safety and desirability of herbicide use in the production of food and wine (Data S1). In European wine regions with strict limits on the number of herbicide passes that can be used in a season, vignerons are aiming to reduce their reliance on herbicides for weed control and under-vine cultivation is enjoying a resurgence (White and Krstic, 2019, p.99). Of course, under-vine cultivation may not suit every soil and situation.

Given the issues noted above, and the dearth of knowledge regarding the growth of desired plant species for cover crops in the under-vine zone, a trial was initiated in 2014 on four commercial South Australian vineyards, representing classical winegrowing regions of the state. Ten cover crop treatments implemented at each site were assessed for a range of parameters including weed suppression, vine productivity and soil biota, which have now been reported in detail (Penfold *et al.* 2017, 2018; Howie *et al.* 2018; Penfold and Howie 2019). For the purpose of this paper, the herbicide Control treatment is matched against three cover crop treatments (straw mulch; medic – a semi-prostrate annual legume mixed with ryegrass; and cocksfoot perennial grass) selected because they produced significant yield differences, differences in establishment costs and they are readily implemented by growers.

Trial sites using randomised, replicated plots compared a clean under-vine zone created using herbicides with nine alternative under-vine treatments tested in one producing vineyard in each of four South Australian wine-grape districts. These focused on commonly grown grape varieties 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 biophysical bases of this paper (above) are reported in objectively measurable quantities recognised in soil science and agronomy (White and Andrew, 2019) rather than 'alternative philosophies'. This gives us some confidence in using these measures as the base for our economic and financial analyses. In the present paper, each district's treatment differences in gross margins are presented in the contexts of variable and fixed costs, and stochastic historical yield and price variations.

We make direct use of district price and yield records published in 12 recent annual '*South Australian Winegrape Crush Survey'* reports (Wine Australia 2017, 2006 through 2017), extracting the detailed district and variety yield and price data for each season. 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 distributions of the Control (herbicide) treatment gross revenues.

Section 2 of this paper quantifies the basis for our stochastic analysis of district gross revenue (yield x price) distributions for the Control (herbicide) under-vine treatment. This allows the calculation of simulated gross margins (in Section 3), as the basis for cash flows specific to each treatment scenario (in Section 4). These cash flows then provide the bases for simulating the related treatment risk profiles by varying the historic treatment yields and prices.

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 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 reveal contrasts among treatments and districts.

Section 4 focuses 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 whole-farm cash flows for the Barossa and Langhorne Creek districts, decadal financial whole-farm risk profiles are generated to show the effects of four levels of opening debt at the farm level;

zero, \$250K, \$500K and \$1M. This process allows estimation of how strongly the choice of under-vine treatment may affect the long-term financial viabilities of the modelled vineyards.

Section 5 concludes noting the nature of our information on differences among treatments regarding grape quality (affecting prices, \$/t), changes in the under-vine soil biome (affecting vine health) and the efficacy of under-vine weed suppression.

2. Gross revenue distributions

In this section, methods for determining gross revenue distributions for each of the study districts over time are explained. These provide the intermediate results forming the basis of the next section on treatment by treatment distributions of gross margins by district.

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 (Table 1). The consumer price indices (CPI) over that period for Adelaide (ABS 2017) were used for this purpose.

The product of the published grape harvest yield per hectare for each year and that year's 2017 adjusted price results in gross revenue values per hectare each year (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.

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. The function 'mvrnorm', in the R (2018) library MASS, was used to decompose the covariance matrix of gross revenues and generate multivariate sequences for 2,400 jointly distributed sets of gross revenues representing the four districts (Table 2). The resulting extended series allows us to plot smoothed results over many more seasons than for the 12-year history. Table 2 compares the longer-term simulated gross revenues with the original 12-year data. The 2,400 sets of simulated 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.

These results show the wide ranges in gross revenues due to price and yield variations, demonstrating the levels of riskiness in the vineyard business. Visually, Figure 3 captures the great year-to-year variability of historical gross revenues mimicked in the longer simulated series. Unsurprisingly, a

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 Shiraz	Eden Valley Shiraz	Lang Ck Cab Sav	Riverland Merlot		CPI all groups, Adelaide Sept-2011 = 100	CPI June 2017 = 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 Shiraz adj price ($K/t)	Eden Valley Shiraz adj price ($K/t)	Lang Ck Cab Sav adj price ($K/t)	Riverland Merlot adj price ($K/t)	Barossa Shiraz Yield (t/ha)	Eden Valley Shiraz Yield (t/ha)	Lang Ck Cab Sav Yield (t/ha)	Riverland Merlot Yield (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.

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 share a market. Positive correlation (r = 0.74) in gross revenues can also be noted between Langhorne Creek Cabernet Sauvignon and Riverland Merlot, and though these districts are separated by over 150 km, they are still part of the South Australian market.

As mentioned above, the district yields and prices reported from 2006 through 2017 are taken to represent those associated with a common method

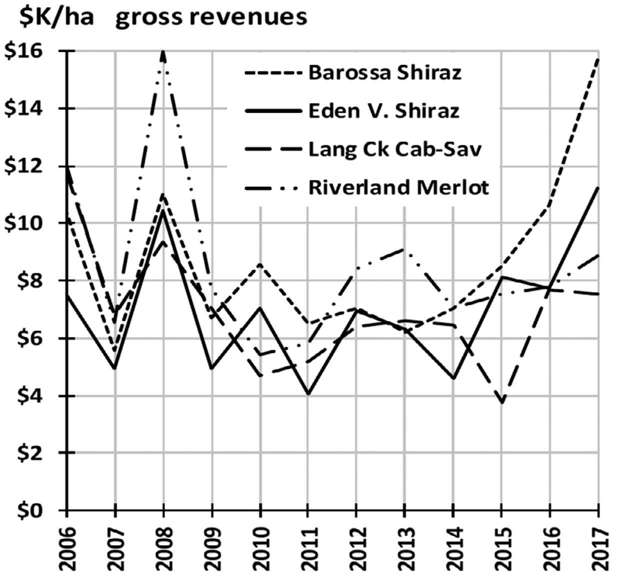

Figure 1 District and variety specific grape harvest Gross Revenues, yields x prices adjusted for inflation (Table 2 values).

of under-vine management: one or more sprays of herbicide each year. Alternatives such as hand weeding, ploughing, cultivating, mowing and sheep grazing 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 many other countries around the world; so much so that 36 confirmed reports of herbicide resistant weeds in grape vines have been documented globally (Heap, 2019).

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 vineyard in Table 3 (such details on Eden Valley, Langhorne Creek and Riverland districts are available as Table S1). We distinguish between the annual costs of the under-vine treatments: triticale straw mulch sourcing and spreading costs; seed and sowing costs of the cover crop treatments; and material and application costs for the herbicide treatment (Table 3). Also listed are the other annual operational costs common across all treatments, considered in calculating the sum of all annual vineyard operating costs for each. Obviously, there are differences in cost between the straw mulch

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

Historical GROSS REVENUE ($K/ha) Yield x Price adjusted for inflation, 2006-2017 [a]					**Simulated GROSS REVENUE ($K/ha)** 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					**Correlations among simulated series**				
	Barossa Shiraz	*Eden V. Shiraz*	*Lang Ck Cab-Sav*	*Riverland Merlot*		*Barossa Shiraz*	*Eden V. Shiraz*	*Lang Ck Cab-Sav*	*Riverland Merlot*
Barossa Shiraz	1				*Barossa Shiraz*	1			
Eden V. Shiraz	0.880	1			*Eden V. Shiraz*	0.864	1		
Lang Ck Cab-Sav	0.406	0.326	1		*Lang Ck Cab-Sav*	0.428	0.355	1	
Riverland Merlot	0.428	0.609	0.743	1	*Riverland Merlot*	0.422	0.628	0.735	1

Covariances					**Covariances**				
	Barossa Shiraz	*Eden V. Shiraz*	*Lang Ck Cab-Sav*	*Riverland Merlot*		*Barossa Shiraz*	*Eden V. Shiraz*	*Lang Ck Cab-Sav*	*Riverland Merlot*
Barossa Shiraz	7.589				*Barossa Shiraz*	7.464			
Eden V. Shiraz	5.189	4.585			*Eden V. Shiraz*	5.167	4.796		
Lang Ck Cab-Sav	2.266	1.415	4.104		*Lang Ck Cab-Sav*	2.417	1.608	4.269	
Riverland Merlot	3.295	3.651	4.212	7.828	*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.

(amortised over 4 years) and annual herbicide treatments. In Table 3, there are differences among seed and seeding costs, amortised over 5 years for the alternative cover crops.

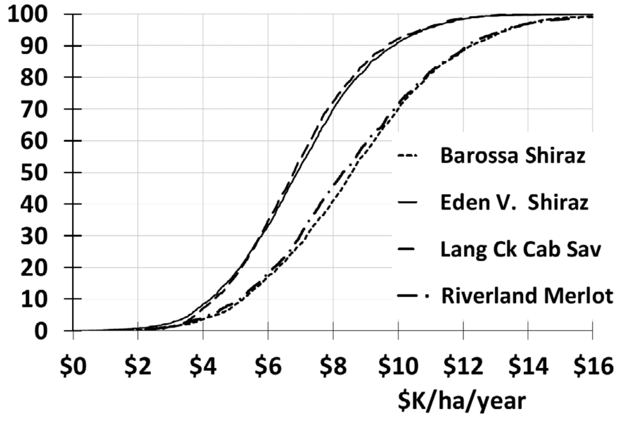

Figure 2 Simulated gross revenues (yields x prices) for wine-grape harvests in four South Australian districts over the 2006–2017 period, expressed as cumulative distribution functions (CDFs) in constant 2017 dollars. In the present study, these CDFs are taken to represent the control (herbicide) treatment 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.

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 gives 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 for Barossa (for the other three districts, see supporting information mentioned above).

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 its respective Control gross revenue. Those for Barossa are carried into the 2nd column in the lower part of Table 3. From each of the Control gross revenues, the alternative treatment gross revenues are calculated (using the mean of each treatment's 2016 and 2017 yield indices), from which the annual operating costs of each alternative treatment are subtracted to arrive at the distributions of gross margin values shown in the lower part of Table 3 for Barossa Shiraz.

Historical yield and price variations, and costs, differ among districts and grape varieties. Our simulated gross margin series sometime dip into negative values (below zero) in Figure 4, with the exception of Langhorne Creek in our examples. Analogous to Figure 2, which plots the CDFs of Control

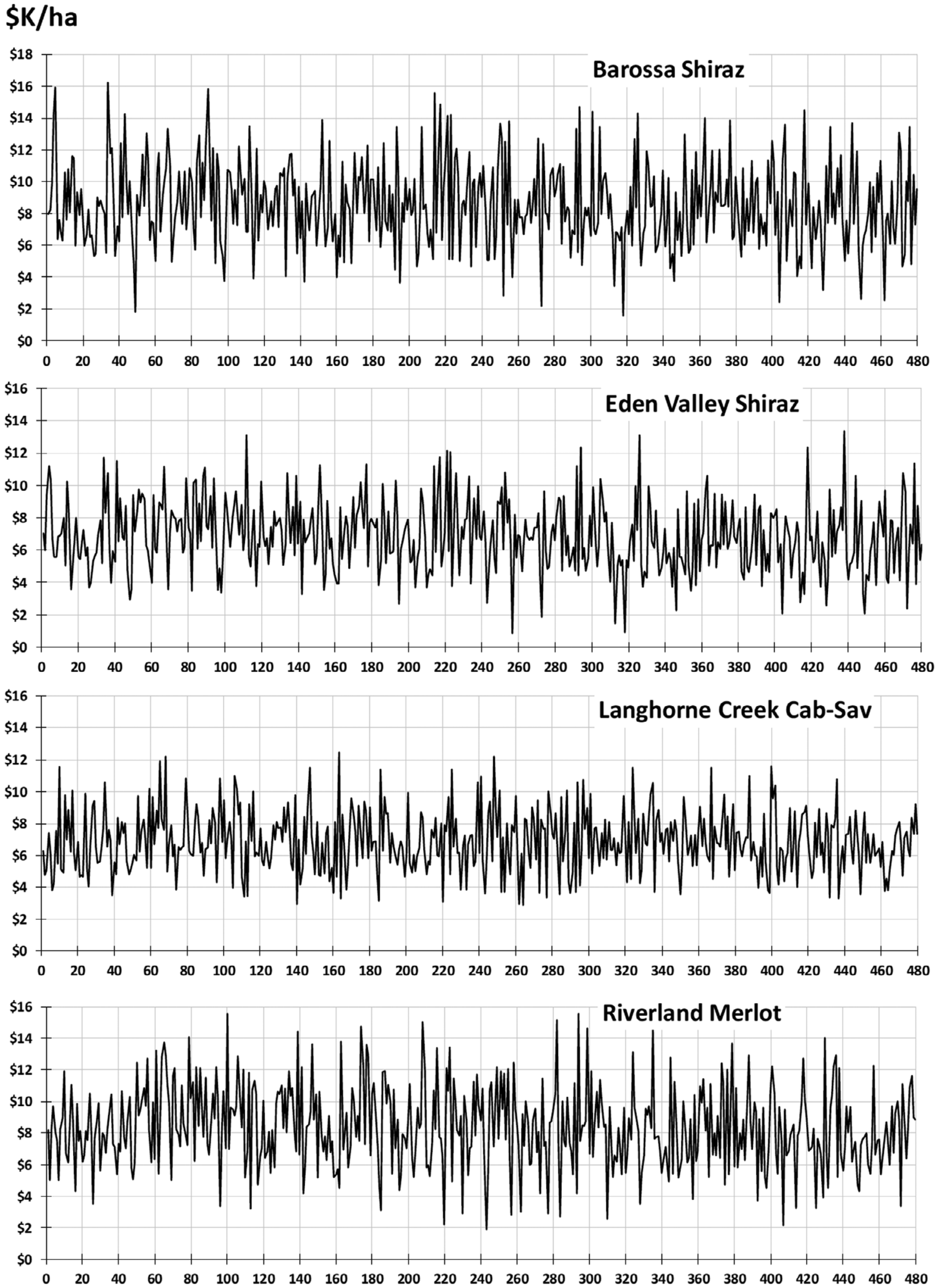

Figure 3 District/variety gross revenues, price x yields ($K/ha) across 480 seasons simulated for under-vine Control treatment (herbicide).

treatment gross revenues for each district, the CDFs of gross margins of the same Control treatments are given in Figure 4 along with their three respective alternative treatment gross margins.

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 4. Between these two extremes are the Control gross margin CDFs of Barossa Shiraz and Langhorne Creek Cab-sav.

The reader will notice the gross margins of only three of the nine alternative treatments are plotted along with the control gross margin distribution for a district in Figure 4. This is for the sake of simplicity in exposition, to avoid crowding the charts. We chose to exhibit only the grass Cocksfoot and a leguminous under-vine planting in each district along with the Control and triticale straw mulch treatments, with an exception for the Riverland where fescue grass replaced the straw mulch. Details of the estimated gross margins of all ten treatments are given for Barossa in Table 3, and for the other three districts in Supporting Information (Table S1).

4. Farm financial risk profiles

We now have the basis for including consideration of the other important whole-farm costs, comprised of any recurring overhead costs, financial costs (such as interest on debts over time, including those incurred in establishing the vineyard or in drought periods) and capital costs (including machinery replacement and costs, living costs and income tax).

Subtracting these costs from the treatment gross margins gives the cash margins, which are used to define long-run risk profiles appropriate for comparing under-vine treatments for a 50-ha vineyard in each of the four districts. These cash surpluses (and deficits) mirror the change in the bank balance resulting from each treatment over decades of yield and price variations, providing more complete whole-farm management information than available from simple gross margin analysis.

To standardise comparisons 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, owner's drawings of \$120K/year, inflation of 3% per year on all the above costs, 6.5% interest paid on outstanding debt, 1.5% interest received on credit balances and 19% taxes on farm income.

A ten-year (decadal) cash flow budget calculator is established in the Excel add-on @RISK (Palisade 2018), which allows Monte Carlo analyses. An opening debt level of (0, \$250K, \$500K or \$1M) is set as a constant for each of the four treatments in a simulation run. The four sets of 2,400 treatment gross margins for the Control (herbicide) and other three under-vine treatments defined for a district (for the case of the Barossa district, the gross margin values with Herbicide, Cocksfoot grass, Medic and Triticale straw, were considered, See Table 3). To clarify the subsequent steps, a schematic example is provided in Data S2. In running the Monte Carlo simulation in @RISK, the number of iterations is chosen (say 10,000). At each iteration, a random number between 1 and 2391 is drawn by cell C15

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

which refers to an address in a lookup table of 2,400 sets of four jointly correlated treatment gross margins 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. This analytical setup was designed following that of Hutchings (2013), allowing repeated simulations of decadal cash margins with @RISK. The idea of decadal samples of time allows accounting for the risk present in the accumulation of debt. Hardaker *et al.* (2015) have clarified the advantages of using appropriately sourced data, summarised as mean values and a variance-covariance matrix to form a 'copula' to generate multivariate series for

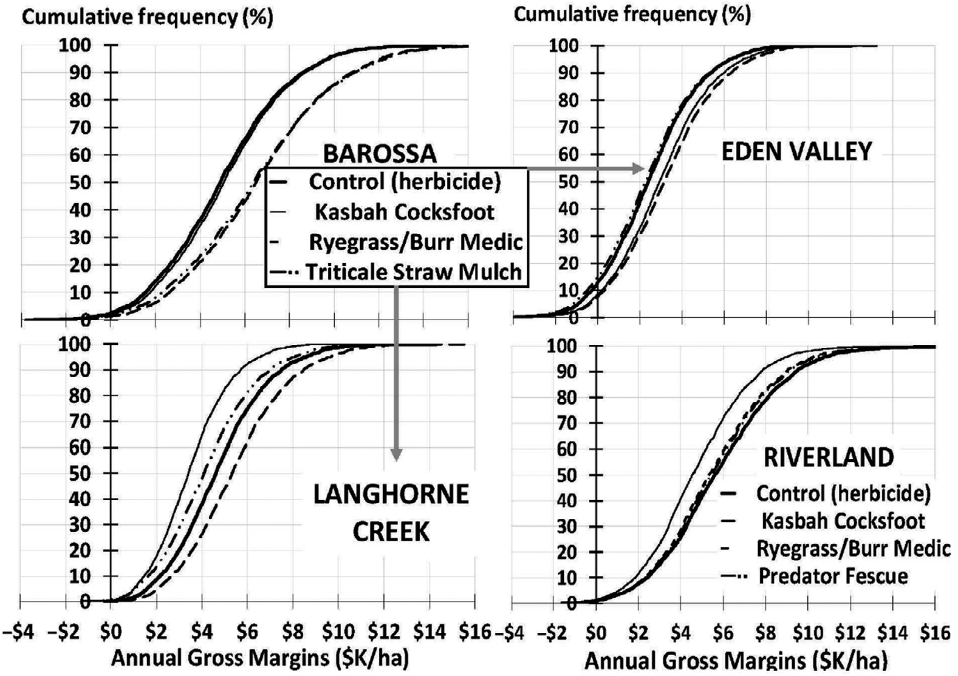

Figure 4 Mean 2016/2017 distributions of gross margins by district and under-vine treatment.

stochastic analysis. We chose to generate our multivariate distributions with R to produce 2,400 random sets of jointly correlated treatment gross margins before importing these into the lookup tables in our @RISK simulator for generating decadal farm financial risk profiles: this comprised our Monte Carlo risk analyses. (Note: Others may choose to use the Copula facility, which is built into @RISK, entering their historical series to directly generate a multivariate series with the same statistical relationships, ready to go for their own Monte Carlo analyses in @RISK.)

From our farm-level gross margins (50 ha × gross margin/ha) are subtracted all the costs mentioned above as they accumulate over each simulated decade. For each district, financial risk profiles were simulated for its four treatments and recalculated for each level of opening debt. The level of opening debt 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 amplifies differences among treatments, largely because debit interest rates are approximately three times greater than credit interest rates. Credit balances can also be taxed, so there is an inbuilt negative bias in long-term cash balances, a point ignored in gross margin comparisons. The brief explanation

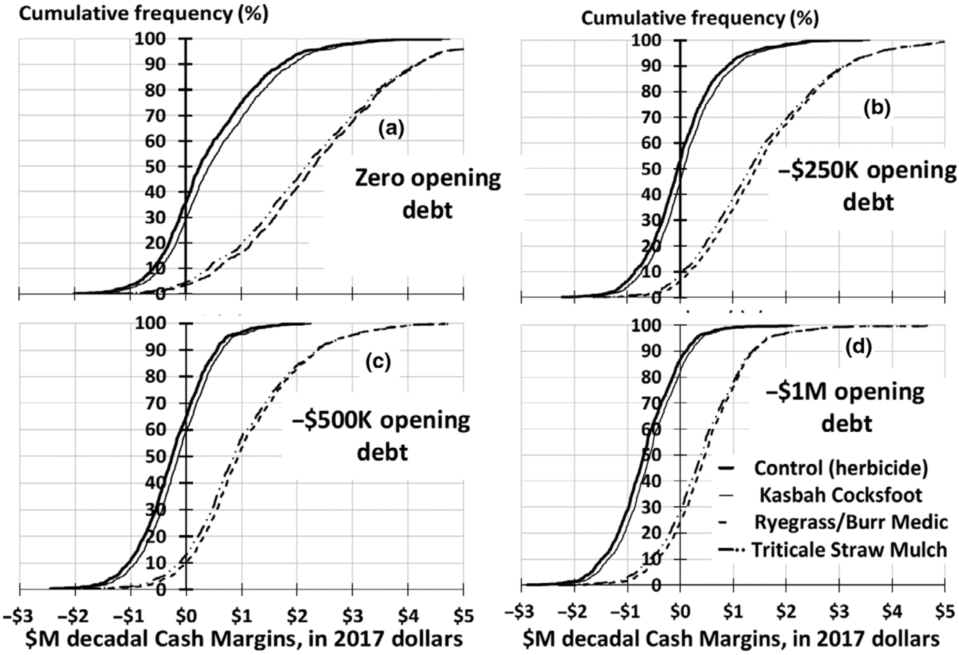

Figure 5 Barossa Valley, financial Risk Profiles for a 50-ha vineyard with four under-vine treatments given four opening debt levels.

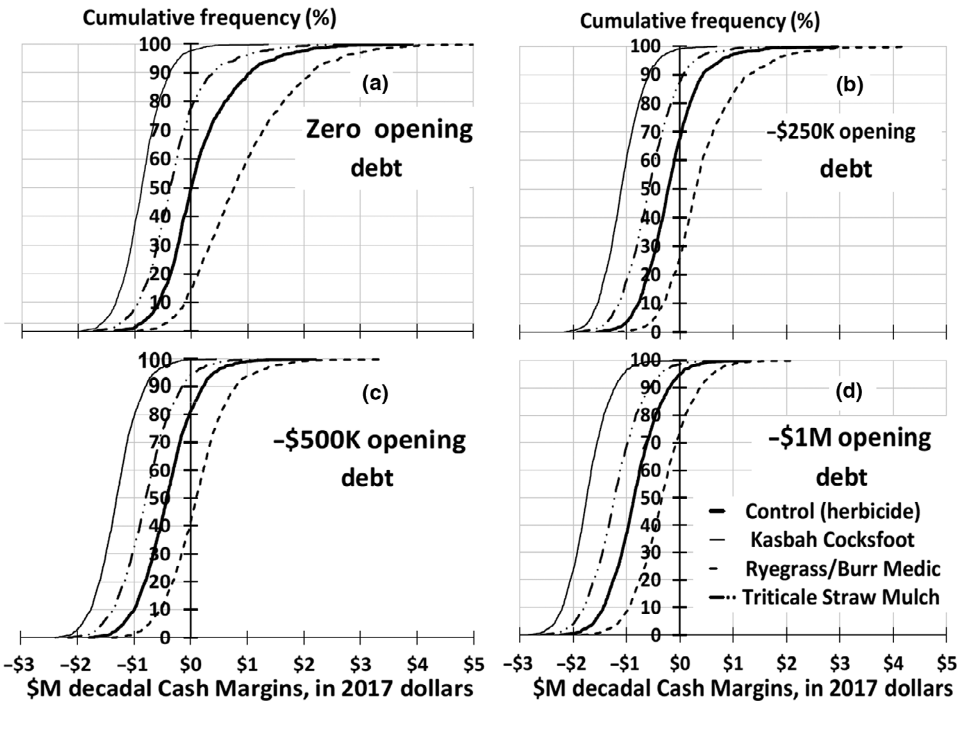

Figure 6 Langhorne Creek, financial risk profiles for a 50-ha vineyard with four under-vine treatments given four opening debt levels.

above should be sufficient for interpreting the results that follow, which are in terms of 'distributions of decadal cash margins'. More simply, we call these whole-farm risk profiles. We present the results for two districts (Barossa and Langhorne Ck), each with four levels of opening debt, in Figures 5 and 6, respectively.

Here, the reader is invited to compare the annual Gross Margin chart for Barossa (Figure 4) with the whole-farm risk profiles of the same treatments (Figure 5a) with zero opening debt. Notice the horizontal axis expresses the ten-year closing bank balance of the vineyard in millions of dollars. The intersect on the vertical axis shows probability of zero decadal cash margin, or the break-even financial return over a decade: the probability of a loss needs to be less than 50% for the business to be viable. Ryegrass/Medic and Straw mulch treatments, which had higher gross margins than the other two treatments, have more than covered the whole-farm costs over time. The other two treatments (Control and Kasbah Cocksfoot) were able to cover the whole-farm costs in only about 65% of decades. With $250K opening debt (Figure 5b), the latter two treatments would only cover costs in about 50% of decades, from which we may infer they are only marginally viable. An opening debt of $1M (Figure 5d) with the Control treatment would see the vineyard losing money in over 80% of decades, while the best treatments would be profitable in 70 to 75 % of decades.

Here, also the reader is invited to compare the annual Gross Margin chart for Langhorne Ck (in Figure 4) with the district's whole-farm risk profiles of the various treatments with zero opening debt (Figure 6a).

As in the case of Barossa results in Figure 5, the Ryegrass/Burr Medic treatment performed very well in the Langhorne Creek vineyard. The risk profile of this treatment with no opening debt (Figure 6a) indicates whole-farm profits in 85% of decades. This decreases to 70% and less than 60% of decades with opening debts of $250K and $500K, respectively (Figure 6b,c). The Control (herbicide) treatment was a distant second best in Langhorne Creek with an indication of profitable operation in only half of the decades with zero opening debt. The triticale straw mulch performed less well and the Kasbah Cocksfoot treatment worse, making losses in about 98% of decades.

We have only shown details of our detailed financial risk profiles results for Barossa and Langhorne Creek vineyards. Our whole-farm financial risk profiles for the Eden Valley and Riverland districts are available to readers in the Figure S1.

It is worth mentioning that under-vine herbicide appeared to be the most profitable treatment in the Riverland trial (as in this treatment's ranking in gross margins, Figure 4). As a possible consequence, vineyards in that district may face higher costs if access to herbicide treatments was to be restricted in the future and no better alternative is found.

The threat of a ban on glyphosate (herbicide), used in production of goods imported to the EU for human consumption after 15 December 2022

(European Commission, 2019), lends a sense of urgency to the need for finding effective alternative means for under-vine management.

5. Conclusions

We believe ours is the first analysis to date that covers the financial risk profiles of alternative under-vine cover cropping or straw mulch treatments to replace common routine use of herbicides. Not only are herbicides facing resistant weeds but export markets may resist their use in crop production. 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. Questions of interest arising from the present analysis include differences among treatments affecting soil health and grape quality (and prices, $/t), perhaps due to changes in the under-vine soil biome (affecting vine health), and to the efficacy of under-vine weed suppression by the different treatments.

With regard to grape quality, the assessments and sensory analysis done so far have shown no detrimental impact on quality from any of the treatments compared to the control (Penfold *et al.* 2018, pp. 27–28). Regarding the soil biome, work remains underway to better define the nature of treatment differences (Penfold *et al.* 2018 pp 6–7; p95), which are known to be pronounced in a number of cases. Botanal data on under-vine pasture yield and composition (Mannetje and Haydock, 1963; Penfold *et al.* 2018, pp. 67–72) support our assumption that the alternative treatments would require no herbicide is roughly correct with the exception of medics at some sites.

The present analysis sheds light 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 each district.

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 Australia2017, 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 understated the profitability of vineyards consistently producing the highest quality grapes.

Fixed and capital costs were subtracted from the gross margins to give annual whole (50 ha) farm accumulated cash flows specific for each of the districts. These cash flows were used to prepare ten-year whole-farm risk profiles for a range of opening debt scenarios using Monte Carlo analysis.

These profiles showed that choices of under-vine treatment could strongly affect the long-term financial viability of a vineyard.

In only one of the districts (Riverland) did the Control (herbicide) treatment appear to be best in terms of gross margins and Financial Risk Profiles. In the other three districts, the herbicide treatment appears second best (Langhorne Creek), third best (Eden Valley) or the poorest option (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 sound that we are confident some alternatives to under-vine herbicide spraying will be financially superior in some districts.

The field trials to date, and our present positive financial indications for some alternative under-vine treatments, should spur investment in expanded field experiments combined with economic and financial assessments from the producers' viewpoints.

Data availability statement

Data are summarised in our Figures and Tables and accessible sources in the reference list. In addition, we have supplied detailed Supporting Information too lengthy to be published in the text. One of our Supporting Information files is a copy of the 'Decadal cashflow simulation' page in our @RISK model that allows readers to understand how our financial risk profiles were generated for each of four under-vine treatments, with four opening debt levels, for each of four South Australian vineyard districts.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Data S1. Herbicide resistance in weeds in grapes, reported in the Southern Hemisphere Herbicide_resistant_weeds_SuppInfo.pdf.

Data S2. An example of our @RISK cash flow worksheet is available as: Decadal cashflow simulation example_SuppInfo.pdf.

Table S1. Gross Margins for Eden Valley, Langhorne Creek and Riverland vineyards are given in Gross_Margin_Tables_SuppInfo.pdf.

Figure S1. Financial Risk Profiles for Eden Valley and Riverland vineyards are given in Financial_Risk_Profile_Figures_SuppInfo.pdf.