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Influence of grape variety, climate and soil on grape composition and on the composition and quality of table wines

by

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Introduction

In recent years, control over the various processes concerned in the making and maturation of wines has been advanced considerably by improvement in both the equipment and the techniques employed in the winery. Such development has certainly raised the over-all standard of wines significantly, but it still remains true that the quality of a wine is very largely determined, or at least is limited by the quality of the grapes from which it is made. The quality of grapes for wine depends on both the variety and the environment in which the grapes are grown. Indeed, recognition of the importance of environment in this connection is the basis of the various commercial classifications of wines according to district of origin and year of vintage.

In the renowned wine areas of Europe, the vineyards are commonly restricted to only a few varieties of grapes which have been chosen because of their suitability for producing high quality wines in the local environment. Choice of these varieties is commonly based on long experience, in some cases extending over centuries, and has been almost entirely empirical. Although information has been published on the influence of temperature on the amounts of sugar, organic acids and colour in grapes (Winkler 1962, Kliewer 1964, Koblet and Zwicky 1965), and considerable data are available on fertilizer applications for specific varieties in specific locations (e. g. Gärtel 1967), there seems to be little, if any, detailed factual information on the influence of different soils on the composition of grapes.

The influences of both soil and climate on the more subtle differences in the composition of grapes, which are so important to wine quality, are little understood. For these reasons, information available from the older wine-producing countries of Europe is of only limited assistance in the selection of suitable varieties for particular soils and climates in other countries. Consequently workers in several such countries have attempted to accumulate, experimentally, information pertaining to their own local conditions. One of the most important investigations of this kind was that of Amerine and Winkler (1944, 1963) who studied the influence of temperature on grapes of various varieties. As a result of their work they divided the State of California into five temperature regions and obtained grapes from each of these regions over a number of years. Comparisons were made between the grapes from different areas on the basis of acidity and total solids content. Wines were made from each of the different parcels of grapes in an experimental winery and these wines were compared by organoleptic assessment and by chemical analysis. From the results of this work and winemakers' observations, recommenda-

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tions have been made regarding the suitability of several varieties for the different temperature regions of California. However, no account of soil differences was reported in the Californian work.

In Australia, some information on the suitability of different varieties for particular localities has been accumulated through the experience of grape growers and winemakers. However, such information is usually confined to a finding that a certain variety did or did not succeed in a particular site, without specifying the site in basic terms. No controlled experiments seem to have been made to compare the composition or the quality of wines made from the same varieties grown on different soils or in different localities.

The work reported in this paper represents an investigation, conducted over a six year period, of the influence of soil and climate on the wine-making quality of grapes. It comprises a study of the behaviour of three important table wine varieties, when grown in different soils and different districts, as regards composition of the grapes and wine-making quality of grapes. Data on phenological characteristics and grape yields are reported separately (Boehm 1970).

Materials and Methods

1. Varieties of grapes

Three varieties *(Vitis vinifera)* were chosen which are quantitatively among the most important of those used for the better quality table wines of Australia. These varieties were Shiraz (identical with the Syrah of the Rhône Valley and the Petite Syrah of Califorina), Riesling (identical with the Riesling of the Rhine Valley) and Clare Resling. This last is a high quality white variety long grown in South Australia, where, until recently it has been called Sémillon but is, in fact, a distinctly different variety. It is most likely of Austrian origin, but has not yet been positively identified.

2. Selection of plots

Triplicate half-acre plots of each variety were selected within established commercial vineyards on each of the two most common vineyard soils in the Barossa Valley and in the Eden Valley districts of South Australia. These two districts were chosen because they are important table wine producing areas; they differ climatically, Eden Valley being cooler and wetter than the Barossa Valley; and they are readily accessible, being within 50 miles of the Australian Wine Research Institute. A further three plots of each of two varieties (Shiraz and Clare Riesling) were also selected in the Berri/Loxton district in the Murray Valley, which is warmer and drier than the two districts previously mentioned, and where the vineyards are irrigated. Plots of Riesling were not available in this district.

The mean monthly temperatures for the three regions are set out in Fig. 1. The data for Nuriootpa are regarded as typical of the area in the Barossa Valley where the grape plots were situated. The rainfall in the three areas conforms to a Mediterranean environment with most of the rain falling in the winter months followed by a hot, dry summer from January through March. The mean annual rainfall for the three areas is as follows:

Eden Valley	(5 year recording)	684 mm	(26.98 inches)
Nuriootpa	(30 year recording)	520 mm	(20.51 inches)
Berri/Loxton	(30 year recording)	528 mm	(10.13 inches)

The quantitiy of irrigation water used at Berri and Loxton depends on various factors, but is between 762 mm (30 inches) and 965 mm (38 inches).

In each instance the plots of the correctly identified variety were chosen for uniformity of the vines and the soils, and for the health and vigour of the vines. The interest of the vineyard owner and his willingness to co-operate in the investigation were also, of course, important considerations.

The soils of the Barossa Valley and the Eden Valley districts have been described in detail by Northcote, Russell and Wells (1954), Northcote and de Mooy (1957) and Northcote (1959), and the vineyard plots used in these investigations were located on typical Red Brown Earth (R.B.E.) and Solodized Solonetz (S.S.) in the Barossa Valley, and on Grey Brown Podzolic (G.B.P.) and Yellow Podzolic (Y.P.) soils in the Eden Valley district. The soils in the River Murray irrigation area were Solonized Brown (S.B.) soils. Since the same soil type was not present in any two districts, the effect of district was confounded with soil type, although the effect of soil type *per se* could be tested within districts. The usual model (Pearce 1953) for the analysis of perennial crop data accumulated over several years was used, and analyses of variance of the following form were carried out on each variate:

Analysis of variance

Variation due to	Degrees of Freedom
Between sites	s—1
Between plots within sites	s(r—1)
Total (between plots)	sr—1
Between years	y—1
years × sites	(y—1) (s—1)
Error	s(y—1) (r—1)
Total	sry—1

The significance of site effects was tested with the main plot error, whilst that for years was tested with the sub-plot error.

3. Harvesting

The vines in the various plots were sampled at regular intervals during the ripening period, using single berry sampling as described by Rankine, Cellier and Boehm (1962), and the progressive increase in the Baumé content (soluble solids) of the juice was measured.

The white grapes were considered to be mature when their Baumé value reached 11 to 12^0 (20 to 21.7^0 Ball or 83 to 91^0 Oe), and the red grapes when their Baumé value reached 11.5 to 13^0 (20.8 to 23.5^0 Ball or 87 to 99^0 Oe). As far as practical, harvesting was carried out at this stage. From each plot 240 kg (525 lbs) of white grapes or 400 kg (875 lbs) of red grapes were picked into wooden boxes, each containing approximately 16 kg (35 lbs). The boxes were transported by road to the experimental winery of The Australian Wine Research Institute and processed as soon as possible, usually on the same day, or at the latest, the following morning. A record was made of the weight of grapes and the number of vines from which they were obtained, in order to calculate yield per acre.

4. Processing

The wine-making procedure was designed to obtain wine which was, as far as possible, representative of the grapes used. All replicate lots of grapes were handled in the same manner and the wine-making procedure was standardized and kept as simple as possible. Special fermenting vessels and temperature-control equipment were designed and built for the purpose, and approximately 40 wines were made each year over the six year period.

(a) White grapes

The grapes were crushed in a beater-type grape mill, which separated the stalks, and the must pumped by a Mono pump directly to a Willmes pneumatic press. The grapes were pressed rapidly at 1 kp/square cm (15 lbs/square inch) pressure, the pressed skins redistributed in the press by rotation and the pressing repeated once. The juice (approximately 136 l or 30 gall) was pumped to one of eight stainless steel cylindrical vertical fermenters 50 cm (20 in) diameter and 150 cm (60 in) high, immersed in a constant temperature water bath of 40 hl (880 gall) capacity maintained at $15^0 \pm 1^0$ C. Sulphur dioxide was then added to give 80 ppm and 4 hours later 4.5 l (1 gall or 3 per cent by volume) of an actively-fermenting culture of a selected pure yeast in sterilized grape juice was added.

The progress of fermentation was followed by daily hydrometer readings and fermentation was normally complete in 2 to 3 weeks. Shortly before fermentation was complete each wine was carefully pumped from its yeast deposit into an 80 l (18 gall) stainless steel cask in a room maintained at 15^0 C, and a fermentation bung fitted to allow exit of the carbon dioxide evolved, but to prevent entry of air. Transfer of the wine at this late stage of fermentation, while it was still charged with carbon dioxide, reduced the risk of oxidation which is common in wines made in small quantities. When the fermentation was complete sulphur dioxide was added to provide 30 ppm in the free state and the wine maintained at 15^0 C. The wine was then racked again from its yeast deposit and this level of sulphur dioxide was maintained until the wine was filtered and bottled at five to six months of age, with no other oenological treatments. The bottles were stored on their sides at 15^0 C until analysed and tasted.

(b) Red grapes

The grapes were crushed and the stalks separated, and the must pumped directly to a vertical fermenter in a water bath at 25^0 C. The same type of fermenters and water bath were used except that the fermenters were 56 cm (22 in) diameter to enable 270 l (60 gall) of must, comprising juice, grape skins and seeds, to be fermented. Sulphur dioxide was added to give 80 ppm and four hours later 9 l (2 gall or 3 per cent by volume) of an actively-fermenting culture of selected yeast in sterilized grape juice was added.

The grape skins rose to the top of the liquid and were mixed with the juice by manual plunging for a fixed time once daily. The progress of fermentation was followed by daily hydrometer readings and the fermenting must was pressed in the Willmes pneumatic press, usually on the fourth day, and the strained juice returned to the fermenter.

Control of temperature of the must with grape skins present was not precise, due to the insulating effect of the cap of skins. The fermenting juice below the cap closely maintained the waterbath temperature of 25°, but the temperature in the cap of skins was somewhat higher, usually between 28° and 31° C. The temperature of the fermenting must after pressing was maintained at 25° C without difficulty.

When fermentation was nearly complete, each wine was pumped into a 160 l (35 gall) American oak cask to which a fermentation bung was fitted, and the fermentation allowed to go to completion. The casks were housed in the 15° C room and all subsequent operations carried out at this temperature. Approximately 45 l (10 gall) of the wine was stored in 4.5 l (1 gall) glass jars for topping up wine in the cask at regular intervals. One month after transferring the wine to the cask it was racked from its yeast deposit into another clean cask and the total sulphur dioxide adjusted to 80 ppm. Further rackings were made at 4 monthly intervals and the wine was bottled into 740 ml (26 fl.oz.) bottles at 18 months of age. The bottles were stored on their sides at 15° until analysed and tasted.

5. Analytical Procedures

A range of analyses were carried out on both the grape juices, which were stored in the frozen state at —7° C, and the wines. In the 6 years of experimentation not all analyses were carried out in every year; some of the results obtained in the early years were found to be of limited value and were discontinued. In addition, other measurements were carried out and are reported separately. These are as follows:

1. Pyruvic acid, α-ketoglutaric acid and acetaldehyde (Rankine 1965, 1967 a, 1969; Rankine and Pocock 1969 a).
2. Malic acid (Rankine 1966).
3. Higher alcohols (Rankine 1967 b).
4. β-Phenethanol and n-hexanol (Rankine and Pocock 1969 b).
5. Influence of yeast strain on wine composition and quality (Rankine 1968).
6. Anthocyanins and tannins (Somers 1967, 1968).

The analytical procedures used are as follows:

1. Ethanol (% v/v) — immersion refractometer reading on wine distillate.
2. Reducing sugar (%) — ferricyanide reduction or Lane and Eynon (Amerine 1960).
3. pH — glass electrode with a Radiometer pH meter.
4. Titratable acid (g/l as tartaric acid) — electrometric titration with standard alkali to pH 8.4.
5. Total cations (meq/l) — electrometric titration to pH 8.4 after passing the wine through a cation exchange resin (Zeo Karb 225 [H]).
6. Tartaric acid (g/l) — colorimetric determination with sodium metavanadate (Amerine 1960).
7. Malic acid (g/l) — manometric decarboxylation using *Lactobacillus arabinosus* (Kolar 1962).
8. Sulphur dioxide (ppm) — Ripper method and later alkalimetric titration (Rankine 1970).
9. Nitrogen (ppm) — microkjeldahl.
10. Phosphorus (ppm) — colorimetric determination after wet digestion.
11. Potassium (meq/l) — flame photometry.
12. Sodium (meq/l) — flame photometry.
13. Calcium (meq/l) — atomic absorption spectrophotometry.
14. Magnesium (meq/l) — atomic absorption spectrophotometry.
15. Extract (g/l) — by calculation from specific gravity of the dealcoholised wine (Amerine 1960).

16. Chloride (ppm) — electrometric titration using silver nitrate.

6. Tasting Procedure

The wines of each year were tasted at about six months of age by a panel averaging five tasters from the staff of The Australian Wine Research Institute. The size of the panel depended on the number of tasters available each year. At the end of the experiment all the wines were tasted using the following procedure:

Three tastings were held daily of wines of the variety Clare Riesling until all these had been tasted, then the wines of the variety Riesling were tasted. The

Table 1

Influence of grape variety and year of vintage on composition of grape juices and wines. Pooled means of triplicate plots from four or five viticultural areas

	Riesling							
	1959	1960	1961	1962	1963	1964	L.S.D.[1]	Mean
Juice								
Baumé °	11.5	11.6	11.9	12.3	12.6	11.7	0.45	11.9
pH	3.12	3.12	3.28	3.21	3.34	3.19	0.05	3.21
N ppm	290	364	446	340	556	—	74	399
P ppm	91	79	120	104	174	—	9	113
K meq/l	35	34	44	39	42	—	4.2	38.8
Na meq/l	3.2	3.3	3.3	3.6	3.4	—	N.S.	3.4
Ca meq/l	3.8	3.9	3.8	3.8	4.2	—	0.36	3.9
Mg meq/l	7.5	7.8	9.0	9.2	11.1	—	0.64	8.9
Cl ppm	—	—	—	—	101	72	22	86
Titr. acid g/l as tartaric	8.8	8.7	8.2	8.2	7.7	8.5	0.40	8.3
Ball/acid	23.9	24.7	26.5	27.7	30.4	25.2	2.0	26.4
Tartaric acid g/l	8.4	8.8	7.9	9.0	7.3	8.8	0.48	8.4
Malic acid g/l	2.4	2.1	2.7	1.7	2.7	2.0	0.31	2.3
Tartaric/malic	3.3	3.7	2.8	5.3	2.7	4.0	0.53	3.6
Total cations meq/l	—	—	—	—	163	173	N.S.	168
Wine								
pH	3.08	3.04	3.25	2.99	3.27	3.02	0.05	3.11
N ppm	106	164	211	122	269	—	39	174
P ppm	57	57	84	70	97	—	6.9	73
K meq/l	17.8	14.2	18.3	13.8	19.3	—	1.5	16.7
Na meq/l	3.5	3.5	3.3	3.6	3.4	—	N.S.	3.5
Ca meq/l	3.6	3.3	2.7	—	—	—	0.46	3.2
Mg meq/l	7.5	7.5	9.0	—	—	—	0.67	8.0
Cl ppm	78	93	122	109	109	80	18	98
Alcohol % v/v	12.8	12.8	13.0	13.4	—	—	N.S.	13.0
Extract g/l	19.9	—	19.9	22.8	20.0	—	2.5	20.5
Titr. acid g/l as tartaric	9.5	8.2	7.1	7.9	7.3	8.8	0.40	8.1
Tasting								
Aroma (score)	3.6	4.6	5.8	6.1	6.3	6.1	0.87	5.4
Flavour (score)	3.7	5.1	6.5	6.8	6.9	7.0	0.74	6.0

[1]) L.S.D. ($P < 0.05$). N.S. = not significant.

(continued from Table 1)

	Clare Riesling							
	1959	1960	1961	1962	1963	1964	L.S.D.[1])	Mean
Juice								
Baumé	11.5	11.2	11.4	11.9	12.0	11.7	N.S.	11.6
pH	3.39	3.43	3.57	3.47	3.53	3.43	0.08	3.47
N ppm	370	501	546	502	646	—	74	514
P ppm	121	88	149	131	172	—	24	132
K meq/l	44	43	58	49	53	—	4.6	49
Na meq/l	3.1	3.1	3.0	3.8	3.2	—	N.S.	3.12
Ca meq/l	3.5	3.2	2.9	3.2	4.2	—	0.38	3.4
Mg meq/l	5.5	6.3	5.7	8.5	9.4	—	0.97	7.1
Cl ppm	—	—	—	—	115	134	N.S.	125
Titr. acid g/l as tart.	6.8	6.3	6.3	6.6	7.2	6.9	0.59	6.7
Ball/acid	32.2	34.2	34.7	33.6	31.4	32.1	N.S.	33.1
Tartaric acid g/l	6.1	6.6	6.3	7.4	6.3	6.8	0.73	6.6
Malic acid g/l	2.9	2.1	2.9	2.0	3.6	2.7	0.40	2.7
Tartaric/malic	2.2	3.3	2.0	4.6	1.7	2.4	0.75	2.7
Total cations meq/l	—	—	—	—	166	154	N.S.	160
Wine								
pH	3.35	3.38	3.57	3.27	3.45	3.29	0.10	3.38
N ppm	152	213	292	326	293	—	48	235
P ppm	68	66	100	79	89	—	14.5	81
K meq/l	25.7	21.1	28.7	21.8	26.1	—	2.7	24.6
Na meq/l	—	2.9	2.9	3.8	3.3	—	N.S.	3.2
Ca meq/l	2.6	2.9	1.9	—	—	—	0.08	2.5
Mg meq/l	5.6	5.7	5.9	—	—	—	N.S.	5.7
Cl ppm	120	—	112	140	126	142	N.S.	128
Alcohol % v/v	12.8	—	12.6	12.6	12.6	—	N.S.	12.7
Extract g/l	18.1	—	16.8	18.3	17.1	—	N.S.	17.6
Titr. acid g/l as tart.	7.0	6.0	5.2	6.4	6.6	7.0	0.64	6.4
Tasting								
Aroma (score)	—	—	6.1	8.0	6.0	5.8	1.24	6.4
Flavour (score)	—	—	6.9	8.7	7.0	6.9	1.30	7.3

wines made from Shiraz were not tasted in this way for reasons given later. Each tasting consisted of seven wines of the same year and comprised one replicate of the triplicate wines made from each of the five soil types. Two of the wines were commercial wines of the same variety, to which numercial scoring values had been allocated, and were designated as such. These wines were used as standards against which the wines in the coded glasses were scored. The wines were allocated points between 0 and 10 for both aroma and flavour, and the scores were kept separate and handed directly to the statistician. In some of the tastings one of the wines was presented twice in order to check on reproducibility of the tasters. This was done without the tasters' knowledge, when some replicates were absent and the spaces were taken by duplicate glasses.

(continued from Table 1)

	Shiraz							
	1959	1960	1961	1962	1963	1964	L.S.D.[1])	Mean
Juice								
Baumé	13.0	13.3	13.0	14.3	13.5	13.0	0.68	13.3
pH	3.44	3.43	3.59	3.58	3.56	3.51	0.05	3.52
N ppm	356	444	431	548	613	—	81	478
P ppm	137	113	152	158	200	—	16	152
K meq/l	43	44	50	51	51	—	4.3	48
Na meq/l	4.4	4.6	4.2	4.6	4.2	—	N.S.	4.4
Ca meq/l	5.4	6.7	4.5	6.2	6.5	—	0.73	5.9
Mg meq/l	9.5	11.4	12.5	12.7	13.0	—	2	11.8
Cl ppm	—	—	—	—	140	126	N.S.	133
Titr. acid g/l as tart.	6.5	6.7	5.9	6.1	6.9	6.4	0.42	6.4
Ball/acid	37.2	37.1	40.0	43.0	37.5	37.7	3.1	38.7
Tartaric acid g/l	5.7	6.5	6.0	6.5	5.9	5.9	0.52	6.0
Malic acid g/l	3.0	2.7	2.8	2.3	—	2.8	0.23	2.7
Tartaric/malic	1.8	2.2	1.9	2.6	1.6	2.0	0.25	2.0
Total cations meq/l	—	—	—	—	163	143	8.9	153
Wine								
pH	3.65	3.63	3.82	3.75	3.68	3.60	0.06	3.69
N ppm	140	204	206	294	260	—	51	220
P ppm	125	114	127	164	167	—	18.5	139
K meq/l	36.7	35.5	40.9	41.7	44.3	—	2.6	39.8
Na meq/l	5.3	6.4	4.8	5.8	5.4	—	1.0	5.5
Ca meq/l	3.0	3.1	2.3	—	—	—	0.13	2.8
Mg meq/l	10.4	11.3	12.1	—	—	—	0.70	11.3
Cl ppm	224	—	282	309	234	221	26	254
Alcohol % v/v	—	—	13.5	14.6	13.8	—	N.S.	14.0
Extract g/l	—	—	25.8	28.5	25.7	—	1.3	26.7
Titr. acid g/l as tart.	7.2	6.8	6.1	6.8	7.2	7.3	0.31	6.9
Tasting								
Aroma (score)	—	—	—	—	—	—	—	
Flavour (score)	—	—	—	—	—	—	—	

Results and Discussion

In the course of the investigation, many thousands of analyses were carried out on the grape juices and wines, and numerous tasting results were obtained on the experimental wines. These results have been summarised in Tables 1 and 2.

1. Grape variety

The three grape varieties differed in several of the constituents measured (Table 1). Riesling grapes contained more acid for a similar sugar content than did the grapes from Clare Riesling, as shown by lower pH, higher titratable acid and lower sugar to acid ratio. Riesling contained more tartaric acid and also less malic than Clare Riesling, and thus had a higher tartaric acid to malic acid ratio. On this basis Shiraz grapes were relatively high in malic acid. Riesling grapes contained less nitrogen, phosphorus, potassium and chloride, and more magnesum, than Clare Riesling grapes.

The differences noted in the juices were also present in the wines made therefrom. The wines made from Shiraz grapes contained more phosphorus, potassium, sodium, magnesium, chloride and extract than wines made from Riesling and Clare Riesling. This indicated that fermentation of Shiraz juice in contact with the grape

Table 2

Influence of viticultural area and soil type on composition of grape juices and wines from three grape varieties.

Pooled means of usually six years from triplicate plots on each soil type

	Riesling					
	Barossa		Eden Valley		Murray Irrig.	
	R.B.E.[2])	S.S.[2])	G.B.P.[2])	Y.P.[2])	S.B.[2])	L.S.D.[1])
Juices						
Baumé ⁰	12.1	12.2	11.5	11.9	—	N.S.
pH	3.25	3.19	3.16	3.23	—	0.05
N ppm	361	384	423	428	—	N.S.
P ppm	106	161	104	82	—	35
K meq/l	40	39	39	37	—	N.S.
Na meq/l	4.5	4.5	2.6	1.9	—	N.S.
Ca meq/l	4.8	4.6	3.3	3.0	—	0.20
Mg meq/l	8.9	7.9	9.1	9.9	—	1.17
Cl ppm	104	87	89	66	—	31
Titr. acid g/l as tartaric	7.5	8.5	9.2	8.1	—	0.89
Ball/acid	30	26	23	27	—	4.0
Tartaric acid g/l	8.0	8.1	9.0	8.4	—	N.S.
Malic acid g/l	1.8	2.5	2.7	2.1	—	N.S.
Tartaric/malic	4.2	2.9	3.4	3.9	—	0.74
Total cations meq/l	158	167	181	166	—	N.S.
Wines						
pH	3.17	3.11	3.04	3.11	—	0.06
N ppm	168	165	190	175	—	N.S.
P ppm	73	119	57	45	—	N.S.
K meq/l	17	17	17	16	—	31
Na meq/l	4.7	4.7	2.6	1.9	—	N.S.
Ca meq/l	3.6	3.3	3.0	3.0	—	0.31
Mg meq/l	7.7	6.9	8.5	8.9	—	N.S.
Cl ppm	115	101	100	78	—	N.S.
Alcohol % v/v	13.2	13.2	12.5	13.1	—	N.S.
Extract g/l	20.7	20.4	20.7	20.8	—	N.S.
Titr. acid g/l as tartaric	7.6	8.4	8.7	7.8	—	0.56
Tasting						
Aroma (score)	5.4	5.6	5.2	5.5	—	N.S.
Flavour (score)	5.9	6.2	5.8	6.1	—	N.S.

[1]) L.S.D. ($P < 0.05$). N.S. = not significant.
[2]) Abbreviations of soil types see text.

(continued from table 2)

	Clare Riesling				
	Barossa		Eden Valley	Murray Irrig.	
	R.B.E.	S.S.	G.B.P. + Y.P.	S.B.	L.S.D.[1]
Juices					
Baumé ⁰	12.7	11.7	11.0	11.4	N.S.
pH	3.62	3.42	3.38	3.52	0.11
N ppm	646	467	570	368	125
P ppm	111	146	136	128	3.4
K meq/l	50	48	47	54	N.S.
Na meq/l	2.5	2.4	2.4	6.6	N.S.
Ca meq/l	4.0	3.2	2.7	4.1	N.S.
Mg meq/l	7.1	7.6	6.7	6.9	N.S.
Cl ppm	58	70	117	286	106
Titr. acid g/l as tartaric	5.3	7.0	7.4	6.6	N.S.
Ball/acid	46	31	28	32	N.S.
Tartaric acid g/l	6.2	6.7	6.8	6.4	N.S.
Malic acid g/l	1.6	2.8	3.0	3.1	N.S.
Tartaric/malic	4.3	2.4	2.4	2.0	1.21
Total cations meq/l	141	161	175	155	N.S.
Wines					
pH	3.50	3.33	3.26	3.50	0.11
N ppm	324	206	262	156	74
P ppm	58	98	81	87	N.S.
K meq/l	25	23	23	28	N.S.
Na meq/l	2.6	2.3	2.4	6.6	N.S.
Ca meq/l	2.1	2.7	2.3	2.9	0.49
Mg meq/l	5.6	6.3	5.4	5.5	N.S.
Cl ppm	73	97	115	250	N.S.
Alcohol % v/v	13.9	12.7	11.9	12.5	N.S.
Extract g/l	17.9	17.7	17.1	17.8	N.S.
Titr. acid g/l as tartaric	5.3	6.7	7.0	6.1	1.17
Tasting					
Aroma (score)	7.8	6.8	6.3	5.0	1.73
Flavour (score)	8.5	7.8	7.3	5.5	1.06

skins extracted more of these constituents from the skins, since the Shiraz juices before contact with skins did not contain unduly large amounts of these constituents, with the exception of magnesium.

2. Year of vintage

The year of vintage had a significant influence on pH, nitrogen, phosphorus, potassium, calcium, magnesium, tartaric acid (Riesling only) and titratable acid in the juices and wines of the three grape varieties. As described above, it was planned to pick grapes at pre-determined Baumé levels. Variations in Baumé between seasons (Table 1) and between sites (Table 2) therefore are a reflection of practical difficulties encountered in judging the approach of these levels or in arranging the picking on the appropriate day. The fact that there is little difference in acid levels of the grape juces between vintages is an indication that the fall in acid during

(continued from table 2)

	Shiraz					
	Barossa		Eden Valley		Murray Irrig.	
	R.B.E.	S.S.	G.B.P.	Y.P.	S.B.	L.S.D.[1])
Juices						
Baumé	14.1	13.4	12.8	13.0	13.4	N.S.
pH	3.54	3.47	3.45	3.42	3.72	0.18
P ppm	347	352	649	601	444	176
N ppm	123	202	155	132	149	55
K meq/l	47	47	45	41	57	5.3
Na meq/l	5.8	6.9	2.7	3.0	3.0	N.S.
Ca meq/l	7.8	6.1	4.9	3.9	6.7	1.80
Mg meq/l	12.2	12.0	11.3	11.0	12.6	N.S.
Cl ppm	155	185	91	108	126	60
Titr. acid g/l as tart.	6.0	6.3	7.3	7.2	5.4	1.00
Ball/acid	43	39	32	34	45	6.9
Tartaric acid g/l	6.1	6.1	6.2	6.2	5.6	N.S.
Malic acid g/l	2.4	2.3	3.0	2.8	3.0	0.47
Tartaric/malic	2.3	2.4	1.8	1.9	1.7	0.44
Total cations meq/l	149	154	166	154	142	N.S.
Wines						
pH	3.71	3.58	3.66	3.60	3.89	0.21
N ppm	172	171	288	269	203	98
P ppm	123	216	143	102	112	64
K meq/l	39	38	40	36	46	N.S.
Na meq/l	7.0	7.9	4.2	3.9	4.7	N.S.
Ca meq/l	2.5	2.7	2.8	2.5	3.4	0.48
Mg meq/l	12.0	11.0	12.0	11.2	10.1	N.S.
Cl ppm	239	372	209	248	202	102
Alcohol % v/v	15.2	14.3	13.1	13.3	14.0	N.S.
Extract g/l	27.0	27.6	28.0	26.0	25.2	N.S.
Titr. acid g/l as tart.	7.0	7.3	7.1	7.1	6.0	0.76
Tasting						
Aroma (score)	—	—	—	—	—	—
Flavour (score)	—	—	—	—	—	—

ripening is closely linked with the rise in sugar. It could be interpolated that, in this set of measurements, there would have been no advantage in measuring acid as well as sugar to assess maturity date, but acidity is now considered an important commercial criterion of grape maturity. Malic acid was lower and tartaric acid was higher in 1962 in each of the three grape varieties. The seasonal characteristics for the years over which the investigation was carried out are shown in Table 3, but variations in acid content are not explicable by the data which we have available.

The levels of minerals in the juice varied significantly between years. There was a tendency in all varieties for minerals, particularly phosphorus, magnesium and nitrogen, to be higher in 1963. The 1962 vintage came from high grape yields resulting from good winter rains and a favourable summer, whereas 1962—63 was an unfavourable year resulting in light crops. These conditions must have had some

Table 3

Summary of seasonal characteristics during the investigation.

Grape crops in the Murray Valley are not dependent on rainfall, and yields are more regular than those in the non-irrigated districts

	Winter	Spring	Summer	Harvest
1958—59	adequate rain	wet and late, poor set at Eden Valley	dry	normal crop, one rain at harvest
1959—60	record low rain	favourable for setting	useful summer rains	low crop
1960—61	adequate rain but ceased early	unfavourable	dry, mild temperatures	light crop in non-irrigated, good crop in irrigated areas
1961—62	favourable	unfavourable	useful rains, cool in January	good crop
1962—63	light rain	unfavourable, some frost damage	dry	light crop
1963—64	favourable	favourable	very dry	good crop

influence on the composition of the juices, but the pattern cannot be seen in the data available. For example, the low crops in 1960 were not accompanied by the same high phosphorus level as in 1963. The vintage year is important in cool areas, particularly in the cooler districts in Australia and in Europe, where the quality of the wines of a particular year is closely related to the amount of solar radiation reaching the vineyard. This is, in effect, a measure of cloud cover, and the best years are commonly the warmest. In such regions grape quality is usually directly correlated with sugar content.

The effect of year of vintage on grape composition is quite complex, and considerable European data are available which have been summarized by Ribéreau-Gayon and Peynaud (1960). Bordeaux workers have studied this question in detail with particular reference to acidity, minerals and other grape components (Peynaud 1946; Peynaud and Maurié 1956) and Ribéreau-Gayon's review (1955) is pertinent. Although the climatic conditions in the South Australian areas studied were much less influenced by the year than cooler European areas, a climatic influence was apparent and the year of vintage had a significant effect on grape composition.

3. Districts and soil types

These comprised three viticultural areas with five soil types (designated "sites" in the analysis of variance) and the results are shown in Table 2. In general the sites had less influence on grape and wine composition than the year of vintage and, although some year × site interactions were significant, these were generally small in relation to the effect of years. A list of the interactions which occurred are given in Table 4. An examination of the interaction tables did not reveal any consistent cause, but rather an erratic pattern of departure from the additive model. The number of interactions was greater for Riesling and Shiraz than for Clare Riesling.

Grapes from all three varieties ripened faster in the Barossa Valley (soils R.B.E. and S.S.) than in the Eden Valley (soils G.B.P. and Y.P.). This would be expected since the Barossa Valley is somewhat warmer (Fig. 1; Boehm 1970). Shiraz grown in the Eden Valley contained considerably more nitrogen, and both Riesling and

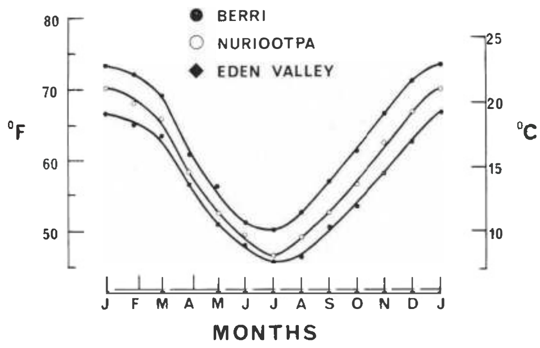
Table 4

Interaction of year with site for various constituents of the grape juice from three grape varieties

Analyses	Riesling	Clare Riesling	Shiraz
Baumé	**	—	—
pH	**	—	***
N	—	*	**
P	***	—	**
K	—	—	***
Na	**	—	—
Ca	—	***	—
Mg	**	—	**
Cl	—	—	*
Titr. acid	**	*	***
Ball/acid	***	*	**
Tartaric	***	—	—
Malic	***	***	***
Tartaric/malic	***	**	**
Total cations	—	—	*

Significance of interactions:
— Not significant ** $P < 0.01$
* $P < 0.05$ *** $P < 0.001$

Fig. 1: Mean monthly temperature for the three viticultural regions.



Shiraz contained less calcium. The two soils in the Barossa Valley influenced grape composition significantly in that the grapes from red brown earth ripened faster than those from solodized solonetz. Riesling and Shiraz grapes grown on red brown earth contained less phosphorus, and Clare Riesling grown on the same soil contained more nitrogen.

The earlier ripening of grapes planted on red brown earth, as compared with solodized solonetz, may be due to soil colour. Red brown earth is a darker soil than solodized solonetz and would absorb more heat, and thus the root zone would be warmer and the grapes would be expected to mature more rapidly. Riesling grapes grown on yellow podzolic soil in Eden Valley contained less titratable acid and had higher pH than the same grapes grown on grey brown podzolic soil in the same location, indicating that the grapes ripened more readily on the yellow podzolic soil.

The significance of soil type in wine quality in various parts of the world is difficult to ascertain from published literature and inspection of vineyard soils. In certain areas where the soil is distinctive, it is claimed that the particular quality of the wines of the area is due to the soil. Whilst this may or may not be true, such a claim has strong propaganda value, and is as difficult to refute as it is to prove. The soils of the Médoc are stated to have an important effect on wine quality, (Seguin 1965) and similar statements are made for other European areas. However soil as an element in wine quality is not considered to be important in California (Winkler 1962). Winkler points out that in the various wine growing areas of the world the soils range from gravelly sands to heavy clay, from shallow to very deep and from low to high fertility. In general, vinifera vines are very adaptable and can grow on a wide range of soils. It is evident that in the renowned vineyard areas of Europe the grape variety, climate and soil combine to produce wines of high quality. A number of the grape varieties of highest quality produce excellent wines when grown on quite different soil types. Also Siegel and Tartter (1961) found no correlation between the levels of certain mineral elements in a soil and those of the musts or wines from grapes grown on it.

The two soils investigated in the Barossa Valley (Red Brown Earth and Solodized Solonetz) were distinctively different, but no difference was apparent in the quality of wines made from the same grape varieties grown on both soils. However, significant differences in grape yields and composition could be demonstrated. From many observations it is our opinion that the important soil features are soil depth, water-holding capacity and drainage, rather than soil composition as such.

The effect of fertilizer application on grape composition was examined in 1962 and 1963 using Shiraz vines at the Nuriootpa Viticultural Station in a replicated experiment in which differences in grape composition could be assessed statistically. Nitrogen and phosphorus were higher in grapes fertilized by these elements, but potassium fertilizer produced no change in the potassium content of the grapes. Phosphate application resulted in higher sodium and chloride in the grapes but the chloride content was markedly depressed when potassium fertilizer was added. Acidity of the grapes was not influenced by any of the fertilizer applications.

4. Irrigation

Interesting differences in composition were found between grapes of the same variety grown in warm irrigated vineyards near the River Murray, yielding 15,000—25,000 kg/ha (6—10 tons/acre) as compared with cooler non-irrigated vineyards in the Barossa and Eden Valley yielding 2,500—7,500 kg/ha (1—3 tons/acre). The pH values of irrigated grapes were significantly higher for the same Baumé readings, but the amounts and proportions of the two principle acids, tartaric and malic, were similar. This indicated a higher level of bases, and is supported in the data by a significantly higher level of potassium. The total nitrogen content of Clare Riesling grapes was considerably lower and sodium and chlorine content higher under irrigation.

Colour readings were carried out on dry red wines from the Barossa Valley and the River Murray irrigation area (Somers 1968), and wines produced without irrigation in the Barossa Valley were considerably darker in colour than wines made from the same variety (Shiraz) grown under irrigation. The amount of colour was usually about 50 per cent more and in some cases up to four fold. It is apparent from our results that, for red wines in particular, controlled or restricted irrigation would be desirable from the view point of wine colour development and wine quality in irrigated areas.

5. Wine quality

There was no significant difference in wine quality between white wines made in the Barossa and Eden Valleys, in spite of their difference in climate and soil (Table 2). The year of vintage, however, significantly influenced wine quality in both areas, with wines made in 1961 to 1964 being better than 1959 and 1960 (Table 1). Where comparisons could be made with the same grape variety (Clare Riesling) in all regions studied including the irrigation area, significant differences existed between both sites and years. In wines made from grapes grown under warm irrigated conditions the average quality was lower than in wines made from grapes grown in cooler, non-irrigated areas.

With respect to red wines one of the findings of this investigation was a realisation of the technical difficulties involved in making reproducible red table wines on pilot-plant scale. Whilst as much care as possible was taken in making and maturing the wines in small oak casks, the colour extraction techniques used were largely empirical and wood aging under reproducible conditions proved difficult. As a result the tasting scores on some of the red wines were a reflection of small but significant variations in colour extraction, in handling and in the casks used to store the wines, although all the casks were made from the same batch of American oak. Consequently the tasting results are not included in the Tables.

Aroma and flavour correlated with each other but did not correlate well with any parameter of juice or wine measured, nor with differences in climate (Table 3). A correlation was apparent, however, with the Ball/acid ratio, in which a high value for aroma plus flavour correlated with a high ratio. This is an interesting observation with possible practical importance. It appears that for dry white wines made from Riesling and Clare Riesling grapes in these regions, the Ball /acid ratio should be above about 25, and can extend to 36.

Summary

The influence of grape variety, soil type, climatic area and year of vintage on grape composition and wine quality was studied over a six-year period with three grape varieties in a co-operative investigation. The wines were made under carefully controlled conditions to eliminate, as far as possible, any effect of winemaking technique. All viticultural and oenological treatments were replicated so that the data could be analysed statistically.

When grapes from different viticultural areas were made into table wines, the quality of the wines was most closely related to grape variety, followed by climatic area and least of all by soil type.

Reproducible differences in grape and wine composition were found for the grape varieties studied. For the same sugar content Riesling grapes and wine contained more acidity and a higher tartaric acid/malic acid ratio than Clare Riesling grapes and wine. They also contained less nitrogen, phosphorus and potassium. Shiraz grapes were relatively high in malic acid.

The year of vintage strongly influenced the tartaric acid/malic acid ratio, particularly for Riesling and Clare Riesling, and also certain other constituents. Certain years could be designated as either high or low malic acid years for a particular grape variety.

The soil type influenced the amounts of certain of the constituents of grapes and wine, but had no significant effects on the wine quality. Wines from the same varieties grown on two widely different soils in the same area could not be differentiated in replicated taste tests. The soil depth, drainage and waterholding capacity appeared to be more important than composition *per se*.

Wines made from irrigated vineyards in the warm River Murray viticultural region, contained similar amounts of tartaric and malic acids, but were higher in pH, than wines made from the same grape varieties in the cooler non-irrigated Barossa Valley. Wines from irrigated grapes were generally of somewhat lower quality than those made from grapes of the same variety grown without irrigation in a cooler area. The time of harvesting irrigated grapes appeared to be critical to achieve the necessary balance between sugar, acid and flavour. Shiraz grapes grown under irrigation contained considerably less colour than grapes of the same variety grown without irrigation.

Aroma was correlated with flavour in assessing wine quality, but numerical values ascribed to these parameters did not correlate generally with the wine constituents measured. A positive correlation existed between high tasting scores and high Ball/acid ratio.

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