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Effect of composted mulch application on soil and wine grape potassium status

K. Y. Chan[A,B,D] *and D. J. Fahey*[A,C]

[A]Centre for Recycled Organics in Agriculture.
[B]Industry and Investment NSW, Locked Bag 4, Richmond, NSW 2753, Australia.
[C]Formerly of NSW Department of Primary Industries, Locked Bag 4, Richmond, NSW 2753, Australia.
[D]Corresponding author. Email: yin.chan@mq.edu.au

Abstract. Oversupply of potassium (K) to grape vines can result in high grape berry K and pH, leading to difficulty in wine making and low wine quality. There is concern that application of mulch to grape vines may increase K supply and the associated risks. The effect of composted mulch from green wastes was investigated in a field trial involving six vineyards in New South Wales on soils commonly used for viticulture production in Australia, over three seasons (2006–08). Significant increases in extractable soil K were detected as a result of mulch application. Higher berry K and pH were also observed due to the mulch treatments, with the changes dependent on season and mulch rate. Increases in berry K were significantly related to the higher soil exchangeable K. The mean increase in berry K due to a mulch rate of 153 m^3/ha was 123 mg/kg. The mean increase in berry pH was 0.02 units observed in two seasons. Application of mulch can increase berry K and pH, but the changes are small compared with variations observed among vineyard sites and between seasons.

Additional keywords: exchangeable potassium, recycled organics, vineyard variability.

Introduction

Potassium (K) is a macro-nutrient important for regulating water movement within the grape vine, and K deficiency in soil can result in reduced vine growth, premature leaf drop, and yield loss (Treeby *et al.* 2004; O'Geen *et al.* 2008). In red grape varieties, adequate berry K is also important in determining berry colour. However, oversupply of K may lead to lower tissue calcium and magnesium and higher grape juice pH (Morris *et al.* 1982; Kudo *et al.* 1998; Mpelasoka *et al.* 2003; Treeby *et al.* 2004). Higher grape juice pH is considered unsatisfactory because it is associated with unstable musts and wine that is more susceptible to oxidative and biological spoilage, and it often produces a wine with low acidity with a flat taste (Mpelasoka *et al.* 2003; Wood and Parish 2003). In addition, excess K in the wine may precipitate as tartrate during cold stabilisation, requiring the winery to adjust the pH to avoid losing an important sensory component of the wine (O'Geen *et al.* 2008).

The positive relationship between K supply and grape K has been established in pot experiments with different K fertilisation levels (Morris *et al.* 1982; Ruhl 1989), but conflicting results have been reported in field experiments (Ruhl 1989). This has been partly attributed to the difficulty in assessing availability of soil K (Mpelasoka *et al.* 2003).

There is a growing interest among vineyard managers to apply mulch in the under-vine area (Agnew *et al.* 2002; Williams *et al.* 2004). Of particular interest is the use of composted mulch from recycled organics such as garden wastes. The composting process minimises the risks of phylloxera, other diseases, and weed infestations. Many benefits of using mulch in vineyards have been reported: water saving, weed control, reduced herbicide use, and yield improvement (Buckerfield and Webster 1998; Biala 2000; Agnew *et al.* 2002). Mulch application can modify the soil environment in several ways, including lowering evaporation loss, thus retaining soil moisture content, and changing soil temperature regime and soil strength. These modifications can all affect root development, and therefore plant growth, as well as impact on soil biological functions such as nutrient cycling and disease incidence (Lanyon *et al.* 2004). In addition, application of mulch on soil can improve water infiltration and, hence, reduce runoff (Louw and Bennie 1992), thereby providing more water for plant growth. However, little research has been undertaken to evaluate effects on the nutrition of grapevines, particularly that of K. Given the high rates of application of mulch and the K content of organic mulch (Agnew and Mundy 2002), the practice may have significant effect on K supply and, consequently, on the growth and production of grapevines and on berry quality. In New Zealand, Agnew and Mundy (2002) reported a 400% increase in soil K as a result of applying mulch containing composted grape marc and a significant increase in grape juice K in one of the two soil types investigated. In South Africa, Fourie and Raath (2009*a*) reported a 325% increase in soil K in a vineyard field experiment when compost was used in place of conventional inorganic fertilisers, resulting in significant increases in K content of grape juice (Fourie and Raath 2009*b*). Given that many Australian vineyard soils are naturally high in K (Treeby *et al.* 2004),

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additional K from mulches may have undesirable effects, but research has not been carried out to investigate the likely magnitude of such impacts.

The objectives of the research reported in this paper are: (*i*) to evaluate the changes in soil K status as a result of application of composted mulch from garden organics; and (*ii*) to relate these changes in soil K to observed changes in berry quality, particularly berry K concentration and pH. The research was carried out over a 3-years period (2006–08) in six vineyards in New South Wales, Australia.

Materials and methods

Location and site selection

The mulch experiment was established at six vineyards in the Cowra/Canowindra (five sites) and Murrumbateman (one site) areas of New South Wales. Background information on the vineyards is presented in Table 1. Four of the vineyards were conventional and the other two were organic. For each vineyard, a block with distinct high- and low-yielding areas was selected and used for the field experiment. Average yield difference of the two areas was 3 t/ha, with the low-yielding areas on average producing only 65% (6 *v.* 9 t/ha) of the high-yielding area.

The six vineyard sites were on three different soil types (Table 1). Of the six sites, three were on Chromosol, two on Kandosol, and one on Kurosol (Isbell 2002). Clay mineralogy of the three soil types is dominated by illite and kandite (Stace *et al.* 1968). According to Maschmedt (2004), they are all common soils used in viticultural production throughout Australia. While there are few limitations in the case of Chromosols, acidity and poor structure may be potential problems for Kurosols and Kandosols, respectively (Maschmedt 2004). With the exception of site 3, where row spacing was 3.6 m, all the other sites had row spacing of 3.0 m.

Experimental design

At each vineyard site there were three treatments, i.e. low mulch, high mulch, and control (farmer's practice), with two replicates. Low mulch refers to mulch applied under the vine row in a band 30 cm wide and 7.5 cm deep, whereas high mulch refers to mulch applied under the vine row in a band 60 cm wide and 7.5 cm deep. The two mulch treatments (low and high) corresponded to application rates of 76.5 and 153 m^3/ha, respectively. For the control treatment in the conventional vineyards, the under-vine area was kept weed-free using herbicides during the growing season. In the case of the organic vineyards, no chemical was used in the control treatment and the weeds were removed mechanically under the vine row during the growing season. The three treatments were repeated in the high- and low-yielding areas of the selected blocks at the six vineyards.

Mulch application

Composted mulch manufactured from garden green-wastes was obtained from a phylloxera-compliant commercial source. The properties of the mulch used in this investigation (Table 2) satisfied the requirements of Australian Standard AS4454 for mulch (Standards Australia 2003). The total K content of the composted mulch was 0.7% (by weight). It had a pH of 7.4 and was high in organic carbon (C) and low in nitrogen (N) (C/N = 87). This is typical of composted mulch produced from garden organics (Chan *et al.* 2007).

The mulch was applied under the vine over the whole of the selected rows in August 2005, using a tractor-driven spreader which had been calibrated to deliver the required amount of mulch for the two mulch rates. The trial was monitored for three seasons (2006–08).

Agronomy and berry measurement

At the beginning of the trial, 10 adjacent vines were selected in each experimental row and tagged for juice quality measurements (treatment plot). Every year, at harvest, 20 bunches were randomly selected from each side of the 10 vines in each treatment plot. Five berries were randomly selected from the top, bottom, and middle of each of the 40 bunches, placed in a plastic container, and stored in freezer for berry quality measurements: pH, titratable acidity, and Brix following Iland *et al.* (2004). For K measurement, the frozen grape samples were defrosted then agitated to regain homogeneity. A 1.3-g subsample was placed into the base of a labelled, pre-weighed polypropylene 50-mL sterile tube with the wet weight recorded, oven-dried at 60°C until it reached a constant mass, and the dry weight recorded. The samples were digested in acid, and the extracts were analysed for K using inductively coupled plasma-optical emission spectrometry (Iland *et al.* 2004). The concentrations of elements were expressed on a fresh berry basis in mg per kg.

Soil sampling and measurement

Soil (0–0.10 m) was sampled during spring in 2006 and 2007 from all sites. From each plot, a composite sample was obtained by combining 10 soil cores randomly located along the vine row. All of the soil samples were analysed for pH, electrical conductivity, total C, total N, and exchangeable cations (Na, K, Ca, Mg, Al) following Rayment and Higginson (1992). Exchangeable cations including exchangeable K were determined following Gillman and Sumpter (1986). Extractable

Table 1. Background information for the six vineyards used in the composted mulch trial

Site	Location	Soil type	Management	Variety	Vine age (years)
1	Cowra (653834E, 6250793N)	Chromosol	Conventional	Chardonnay	23
2	Canowindra (643855E, 6281758N)	Kandosol	Conventional	Chardonnay	11
3	Murrumbateman (690158E, 6123560N)	Kurosol	Conventional	Cabernet sauvignon	8
4	Canowindra (650250E, 6279803N)	Chromosol	Organic	Shiraz	4
5	Canowindra (648477E, 6283359N)	Kandosol	Conventional	Shiraz	8
6	Canowindra (649761E, 6280216N)	Chromosol	Organic	Merlot	6

Table 2. Characteristics of the composted mulch used in the vineyard trial

Soil properties	Mean value
pH units	7.4
Electrical conductivity (dS/m)	1.54
Soluble P (mg/kg)	1.6
Total P (%)	0.135
Total K (%)	0.70
NH_4-N (mg/kg)	0.9
NO_3-N (mg/kg)	0
Total N (%)	0.60
Total C (%)	52
C : N	87
Particle size grading (%): <16 mm retained, >16 mm retained	48, 52
Glass, metal, rigid plastic >2 mm (%)	0
Light plastic >5 mm (%)	0.04
Stones and lumps of clay ≥5 mm (%)	11

K of soil samples collected in 2006 was also determined using the Colwell bicarbonate extraction method (Rayment and Higginson 1992).

Statistical analyses

Results of berry K, berry pH, and soil exchangeable K for all the treatments were analysed separately and fitted with a linear mixed model as follows:

$$\text{Data} = \text{Fixed (Area + Treatment + Area : Treatment)} \\ + \text{Random (Vineyard + Vineyard : Area} \\ + \text{Vineyard : Area : Replicate + Vineyard :} \\ \text{Area : Treatment + error)}$$

where the terms within 'Fixed' are assumed to have fixed effects and the terms within 'Random' are assumed to have random effects. 'Area' refers to the high- and low-yielding areas of each vineyard, 'Treatment' to the different mulch treatments, and 'Vineyard' to the different vineyard sites. All parameters were estimated using the residual maximum likelihood (REML) technique and the analysis was run on ASRemL statistical software (Gilmour *et al.* 2005). Means were compared using the least significant difference (l.s.d.) test at $P = 0.05$ when the F-test showed significance.

Results

Statistical analyses showed no significant difference in soil and grape parameters between the high- and low-yielding areas, so the average results from both areas are presented. Comparing the mulch and control treatments two years after application of composted mulch, soil measurements indicated significant differences in a range of soil properties: total C, total N, exchangeable cations (except Mg), and effective cation exchange capacity (ECEC) (Table 3). However, the mulch treatments did not significantly alter soil pH. Application of mulch significantly increased soil C level. The increase in total C was 26% and this was similar between the low and high mulch treatments. The mulch treatments significantly increased ECEC of the soil when compared with the control. Among the exchangeable cations, K had the largest percentage increases due to mulch treatments, average 79%, and similar for low and high mulch treatments. Mulch application also increased exchangeable Ca and Na but the effects were significant only in the high mulch treatment (Table 3). Examination of the exchangeable K values of the control soils indicated a wide variation in concentration among the six vineyards (Table 4). For instance in 2006, exchangeable K ranged from 0.31 cmol(+)/kg at site 3 to 1.23 cmol(+)/kg at site 5, a nearly 4-fold difference.

Of the berry quality measurements, no significant differences were detected between the different treatments for titratable acidity and Brix for all three seasons (results not shown). However, mean berry K was significantly ($P < 0.05$) higher under the high mulch treatment than the control for all three seasons (Table 5). In 2006, mean berry K concentrations under both mulch rate treatments were similar, and both were significantly ($P < 0.001$) higher than the control. The difference in berry K concentration between high mulch and the control treatments was similar across the three seasons, at 141, 114, and 114 mg/kg for 2006, 2007, and 2008 seasons, respectively. These variations were considerably smaller than the ranges of berry K concentration observed among the different vineyard sites. In the 2006 season, the difference in berry K concentration among the vineyard sites for the control treatment ranged from 1720 mg/kg at site 3 to 3700 mg/kg at site 4 (Table 5). Mean berry K concentration also varied with season; for example, for the control treatment, berry K ranged from 2877 to 3268 mg/kg, being highest in 2007 and lowest in 2008.

Mean berry pH under both mulch treatments was significantly ($P < 0.05$) higher than the control in 2006 and 2008, but not in 2007 (Table 6). In both the 2006 and 2008 seasons, the berry pH from the two mulch treatments was similar and 0.02 pH units higher than that of the control. However, seasonal variation in berry pH for the control was 0.18 units (highest pH observed was 4.34 in 2006 and lowest 4.16 in 2008).

Table 3. Average changes in soil properties (0–0.10 m depth) under different treatments sampled in August 2007
ECEC, Effective cation exchange capacity. Within columns, means followed by the same letter are not significantly different at $P = 0.05$; n.s., not significant ($P > 0.05$)

Treatment	pH_{Ca}	N (%)	C	Ca	K	Mg (cmol(+)/kg)	Na	ECEC
Control	7.10	0.18a	1.65a	7.97a	0.62a	3.27	0.23a	12.03a
Low mulch	7.13	0.18a	1.97b	8.66b	1.02b	3.46	0.33b	13.42b
High mulch	7.08	0.20b	2.17b	9.26c	1.19b	3.61	0.36b	14.32c
l.s.d. ($P = 0.05$)	n.s.	0.02	0.27	0.59	0.23	n.s.	0.06	0.88

Table 4. Range and mean (cmol(+)/kg) soil exchangeable potassium concentrations and bicarbonate-extractable potassium concentration in the 0–0.10 m layer for the different mulch treatments in the six vineyards included in this investigation
Within columns, means followed by the same letter are not significantly different at $P=0.05$

Treatment	Exchangeable K				Bicarbonate K	
	2006		2007		2006	
	Range	Mean	Range	Mean	Range	Mean
Control	0.31–1.23	0.64a	0.28–1.10	0.62a	0.45–1.33	0.77a
Low mulch	0.58–1.78	1.04bc	0.45–1.80	1.02b	0.72–1.90	1.16b
High mulch	0.64–2.19	1.14c	0.43–2.03	1.19b	0.81–2.29	1.24b
l.s.d. ($P=0.05$)		0.09		0.23		0.31

Table 5. Average potassium content of grapes (mg/kg wet weight basis) under different mulch treatments in 2006–08 from the different vineyards
Within columns, means followed by the same letter are not significantly different at $P=0.05$

Treatment	2006		2007		2008	
	Range	Mean	Range	Mean	Range	Mean
Control	1720–3700	3077b	2200–4600	3268b	2100–3200	2877b
Low mulch	2100–3900	3208a	2200–4900	3336ab	2400–3300	2905b
High mulch	2200–3700	3221a	2200–4600	3382a	2500–3600	2991a
l.s.d. ($P=0.05$)		74		80		66

Table 6. Average pH of berry juice from different mulch treatments for three seasons (2006–08) from the different vineyards
Within columns, means followed by the same letter are not significantly different at $P=0.05$; n.s., not significant ($P>0.05$)

Treatment	pH		
	2006	2007	2008
Control	4.34b	4.23	4.16b
Low mulch	4.36a	4.22	4.19a
High mulch	4.36a	4.22	4.18a
l.s.d. ($P=0.05$)	0.02	n.s.	0.02

Regression analysis indicated highly significant positive relationships between berry pH and berry K in two of the three seasons, 2006 and 2008:

2006 vintage:

$$\text{Berry pH} = 3.14 + 0.000382 * (\text{berry K}) \quad (r^2 = 0.89;\ n = 72;\ P < 0.001)$$

2007 vintage:

$$\text{Berry pH} = 4.74 - 0.000121 * (\text{berry K}) \quad (r^2 = 0.09;\ n = 66;\ \text{n.s.})$$

2008 vintage:

$$\text{Berry pH} = 3.12 + 0.000359 * (\text{berry K}) \quad (r^2 = 0.67;\ n = 66;\ P < 0.001)$$

For the 2006 and 2007 samplings, the mean exchangeable soil K concentrations were similar under the two mulching treatments, which were almost double the control (Table 4). These differences were significant ($P<0.05$) for both samplings. However, from the ranges, soil exchangeable K in the 0–0.10 m layer among the six vineyards varied by up to >1 cmol(+)K/kg (Table 4).

Regression analyses indicated significant positive relationships between berry K and soil exchangeable K for both 2007 and 2008 seasons:

2007 vintage:

$$\text{Berry K} = 2681.8 + 519.6 * \text{soil } K_{06} \quad (r^2 = 0.43;\ n = 72;\ P < 0.0001)$$

where soil K_{06} refers to soil exchangeable K concentration of the 0–0.10 m layer measured in 2006.

2008 vintage:

$$\text{Berry K} = 2572.6 + 375.7 * \text{soil } K_{07} \quad (r^2 = 0.60;\ n = 66;\ P < 0.0001)$$

where soil K_{07} refers to soil exchangeable K concentration of the 0–0.10 m layer measured in 2007.

Bicarbonate-extractable K (Colwell method) results of soils collected from the different treatments and different vineyards in 2006 followed the same trend as soil exchangeable K results (Table 4). In fact, regression analyses indicated that the two measurements were highly correlated:

$$\text{Bicarbonate K} = 0.148 + 0.967\text{exK} \quad (r^2 = 0.98;\ P < 0.0001)$$

where bicarbonate K is the extractable K concentration (cmol/kg) using the Colwell method and exK is exchangeable K concentration (cmol/kg) using the Gillman and Sumpter method (Rayment and Higginson 1992).

Discussion

Soil exchangeable K concentrations detected in the vineyard soils were high compared with those recorded for Australian soils and varied widely among the six vineyard sites. The wide range of exchangeable K could be a reflection of different clay mineralogy, clay percentages, and organic C levels found in the soils of the different vineyards (Gourley 1999). Illite, the clay type particularly high in available K (Gourley 1999), while existing in all three soil types, may be present in different concentrations, thus contributing to the observed different soil exchangeable K concentrations. Australian soils are generally high in K, except for leached acidic soils (Treeby *et al.* 2004). According to those authors, bicarbonate-extractable K of >100 mg/kg (>0.26 cmol/kg) is normally considered adequate for vine nutrition. Our results indicated that bicarbonate K concentrations of all the soils were greater than this concentration, even in the control (Table 4), and therefore none of the soils was likely to be deficient in K. Gourley (1999) suggested that critical values of K in surface soils are similar for most agronomically important plant species and are generally around 0.2–0.5 cmol(+)/kg. This confirms the report by Treeby *et al.* (2004) that many vineyard soils in Australia are naturally high in K. Furthermore, while the literature appears to suggest that similar critical K concentrations are obtained using different laboratory measures (Gourley 1999), our results indicated that the two methods used to measure K produced results that are significantly related but not similar in values, with the bicarbonate K consistently higher than exchangeable K. More research is needed to develop a standard method of soil K measurement that is biological meaningful.

Our results established a significant positive relationship between berry K and soil exchangeable K. The generally high berry K observed in all the vineyards for all the seasons could therefore be accounted for by the fairly high soil K concentrations (Treeby *et al.* 2004). Furthermore, the higher berry K found under the mulch treatments compared with the control was related to the higher soil exchangeable K concentration. Similarly, higher berry K was reported by Fourie and Raath (2009*b*) for compost-treated soil in a vineyard in South Africa compared with conventional inorganic fertiliser treatment in three of five seasons. Those authors attributed the elevated soil K to the practice of using compost at rates necessary to supply a sufficient amount of N to the grapevines, thereby resulting in oversupply of K and P in the topsoil layer.

The present results also established a significant link between high berry K concentration and higher pH of the berry juice as a result of mulch application in two of the three seasons monitored. The high pH results from the substitution of K^+ for H^+ in the grape tissue and is a particular problem for warm production regions such as some parts of Australia and USA (O'Geen *et al.* 2008). Lack of significant relationship between berry K and pH in the 2007 season could be due to the unseasonal dry conditions, with exceptionally low in-season rainfall. As indicated in Table 7, while rainfall for the 2006 and 2008 seasons was fairly close to the long-term averages, it was only 40–65% of the long-term averages for the six sites in 2007.

High pH in grape juice can cause problems in the wine-making process (Agnew *et al.* 2003) as well as reducing the wine quality by decreasing the colour quality of red wines (Somers 1975). Morris *et al.* (1982) reported that high K lowered the acid content of the juice and caused a reduction in colour difference metre value (CDM) 'b' values and an increase in CDM hue (a/b) values by changing the structure of the anthocyanin molecule without having an effect on anthocyanin content. The high K level of Australian wines is probably a consequence of the generally high soil K level of Australian vineyard soils. According to Somers (1975), Australian red wines tend to have pH >3.7 (above the optimum pH range of 3.3–3.7). This is related to the high K concentrations (27–71 mmol/L) compared with average values of K for overseas red wines (22–32 mmol/L) (Somers 1977).

Table 7. In-season rainfall (mm) at the six vineyard sites for the 2006–08 seasons

Rainfall between September and the following March for all sites except site 3, which was rainfall between September and the following April; LTA, long-term average in-season rainfall

	2006	2007	2008
		Site 1	
Actual	429	201	270
LTA	389	389	389
		Sites 2, 4, 5	
Actual	412	142	348
LTA	359	359	359
		Site 3	
Actual	387	241	442
LTA	373	373	373

Our results indicated that mulch application resulted in significantly higher berry K and, in turn, higher berry juice pH, resulting in increased K/H^+ ratio and therefore potentially adverse effect on the fermentation process (Kudo *et al.* 1998). However, the magnitude of grape juice K increase (~4%) due to mulch application reported in this investigation was lower than reported by Agnew *et al.* (2003) in New Zealand. Those researchers reported a range of increase in grape juice K of 7.1–18.3% at four sites over three seasons as a result of mulch application. Those higher results could be due to the use of mulch containing grape marc, which contains a higher level of K than green wastes.

In the present investigation, the impact of mulch application on wine quality resulting from higher berry K concentration is not certain but likely to be small, based on the observation that grape juice K concentration was fairly high even in the control (>1720 mg/kg, range 1720–4600 mg/kg) (Table 5). According to Agnew *et al.* (2003), a juice K concentration of 900–1300 mg/L is desirable for wine making; given that the specific gravity of grape juice is >1.0, their suggested desirable K concentration range in mg per kg would be slightly lower. Based on this, the grape juice K concentration found in our control treatment exceeded the desirable range, i.e. even in the absence of mulch application.

The increase in pH (0.02) due to mulch application is considerably smaller than reported by Mundy and Agnew (2002), namely 0.07–0.12 units. Furthermore, the likely adverse effect of mulch on wine quality has to be assessed in the context of the observed seasonal and site variations. The increases in berry K concentrations (114–140 mg/kg) due to mulch application were small when compared with the natural variation among the different vineyards. For example, for the control in 2006, the range of berry K concentrations found among the vineyards was 1720–3700 mg/kg (Table 5) and mean berry K among the three seasons (2006–08) ranged from 2877 to 3268 mg/kg (Table 5). Based on these results, the observed increases in berry K concentration as a result of mulch application were only equivalent to 6% and 31%, respectively, of the variations due to vineyard location and season.

Furthermore, there are practical precautions that can be taken to minimise any likely adverse effect as a consequence of mulch application by reducing K supply and uptake by grapevines (Mpelasoka *et al.* 2003). First, this can be achieved by more careful site selection to avoid sites with high soil K content. This is highlighted by the finding that a wide range of soil K (3–4-fold) measured both as exchangeable and bicarbonate-extractable K was encountered in the six vineyards included in this investigation. O'Geen *et al.* (2008) also proposed the practice of K management regions based on soil characteristics, particularly the soil K status in the Lodi Winegrape District in California. Second, the impact of high K supply due to mulch application can be reduced by using rootstocks with lower K uptake (Mpelasoka *et al.* 2003) as well as avoiding red grape varieties. The latter is in view of the potential adverse effect on wine colour, which tends to be a more important consideration for red wines. Finally, the possibility of K oversupply to grapevines during the season can be reduced by K fertiliser and irrigation management. Water availability to the vines can affect K availability and therefore berry K and pH (Dundon and Smart 1984). However, all of these measures require a good understanding of the K status of the vineyard soils and a better understanding of the K supply and grape juice K relationship of our Australian vineyard soils.

Conclusions

The application of composted mulch from garden organic wastes (at a rate of 153 m^3/ha) led to significant increase in K content and pH of grape juice. The increases were related to the higher soil exchangeable K in the mulch-treated soils. However, the increases in berry K concentration and pH were both small compared with the natural variations among vineyards and seasons. To minimise the possible adverse effects on grape berry and wine quality, it is advisable to avoid mulch application on soils with inherent high K status, via careful site selection. Furthermore, adverse effects of high K can be minimised by practical precautions, namely choice of grape varieties, use of rootstocks, as well as irrigation and nutrition management. Finally, the long-term effects of using recycled organics such as mulch and compost in vineyards on soil nutrient balance and grape production and quality warrant further investigations (Fourie and Raath 2009*b*).

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