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Effect of incorporated or mulched compost on leaf nutrient concentrations and performance of *Vitis vinifera* cv. Merlot

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Abstract

Compost can reduce evaporation and increase nutrient uptake by plants, but it is not clear if it can increase soil water holding capacity or stimulate leaf gas exchange, water use efficiency and yield of vines. To study these effects, compost from garden and food waste was incorporated or mulched in a vineyard at a rate of 100 m³ ha⁻¹, three months before the measurements. The vineyard received irrigation during spring and summer. Soil water content was monitored regularly with a capacitance probe. Photosynthesis, transpiration, stem water potential and leaf area index were measured several times during the vegetation period. At harvest, yield, berry weight and quality as well as chlorophyll, N, P and K concentrations in leaves were determined. Only mulched compost increased soil water content at 10 cm depth, but the water content in the deeper layers was not affected by compost addition. Compost also did not affect transpiration rate and stomatal conductance during the vegetation period, but mulched compost increased the photosynthesis per plant at flowering, pea size and maturity periods. Compost amendment, particularly mulching, increased yield, specific berry weight, and leaf N and P concentrations, and reduced the number of chlorotic leaves at harvest. Berry quality was not affected by compost amendment. It can be concluded that mulched compost has a positive effect on grapevine yield and can be an alternative fertiliser source for vines with no adverse effect on berry quality.

Keywords: Gas exchange, grapevine, organic amendment, mulched compost, soil water content

1. Introduction

Plant water availability is an important limiting factor for current and future viticulture, particularly because a large proportion of the area used for viticulture is located in semi-arid climates. In addition, the growth period of grapevines often coincides with the dry period during which there is a higher atmospheric demand for water. Therefore, many growers have to rely more and more on irrigation to obtain adequate yields. Climate change

modelling indicates an increase in aridity in the current growing area which could help a negative effect on yield and quality of grapes (Chaves *et al.*, 2007).

Compost is widely used in agriculture and horticulture, and it has been recently trialled for grapevine (Pinamonti, 1998; Korboulewsky *et al.*, 2004; Powell *et al.*, 2007).

The general benefits of compost addition are increasing soil water holding capacity (Aggelides and Londra, 2000; Curtis and Claassen, 2005; Mylavarapu and Zinati, 2009), providing nutrients and organic matter, as well as improving soil physical properties, including soil structural stability (Tejada *et al.*, 2009), total porosity (Jamroz and Drozd, 1999; Aggelides and Londra, 2000), aggregate formation (Celik *et al.*, 2004; Sodhi *et al.*, 2009) and hydraulic conductivity (Curtis and Claassen, 2009). Therefore, compost application could be useful in vineyard management to increase water use efficiency and reduce irrigation requirements. Furthermore, mulched compost can reduce evaporation from the soil surface, fertiliser leaching and weed growth (Pinamonti, 1998; Biala, 2000; Campell and Sharma, 2003). However, it is unclear if compost can increase soil water content and has beneficial effects on gas exchange and yield.

The aim of this study was to assess the effect of compost application on soil water content, gas exchange and yield of field grown grapevines. Our hypothesis was that compost application would increase soil water content, and therefore affect gas exchange, and improve yield and water use efficiency. Compost was applied as mulch or incorporated to determine if these two common methods of compost application differ in their effect. Compared to incorporated compost, mulched compost may reduce evaporation more strongly but may provide less nutrients.

2. Materials and Methods

2.1. Experimental site

The experiment was carried out in a 6-year old Merlot vineyard located at the Waite campus of The University of Adelaide (34°58'S, 138°37'E). The climate is Mediterranean with wet winters and hot dry summers. The soil is a clay loam at 0 to 40 cm (Table 1) which overlays a heavy clay at 50 to 90 cm depth. The shoot was vertically positioned from

flowering onwards and was trimmed only if required to accommodate bird nets at veraison. Sulfur and copper were used to protect against powdery and downy mildew, respectively. The vineyard was planted with 1.8 m between plants and 3 m between rows, with rows orientated in a North to South direction. The vines were drip-irrigated three times per week for 4 hours from October - April (growing season) when required (i.e. 2 L h⁻¹) equivalent to 1.5 mega litres ha⁻¹ season⁻¹.

2.2. Treatments

Compost from garden (prunings and lawn clippings) and food waste (14% > 5 mm, 86% ≤ 5 mm, pH_{water} 8.0, EC_{1.5} 1.6 mS cm⁻¹, total N 12.7 g kg⁻¹, P 2.04 g kg⁻¹, and organic C 114 g kg⁻¹, available N 25.3 mg kg⁻¹ and P 236.5 mg kg⁻¹) was collected from a local commercial producer. Treatments were unamended (control) and amended at 100 m³ ha⁻¹ compost either incorporated (incorporation) or mulched (mulch) with 4 replicates per treatment. Compost was applied to three consecutive vines, but the data was only collected from the middle vine; two others were buffers. Compost was incorporated or mulched as a 60 cm wide bench of 5 cm thickness beneath vines in the first week of February, 2011 (i.e. three months before the first measurement of soil water content). Compost was spread on the soil surface for mulch or mixed with 0 - 7 cm of the top soil using a shovel and a garden fork for the incorporation treatment.

2.3. Measurements

Soil water measurement

Soil water content was measured from three months after compost application onwards with a portable soil water monitoring system (capacitance probe, Diviner 2000, Sentek Pty Ltd., South Australia) at 10, 20, 30, 40, 50, 70 and 90 cm depth (Fares and Alva, 2000; Starr and Paltineanu, 2002). The access tubes were installed up to 100 cm soil depth (Geesing *et al.*, 2004) Three tubes were installed for each middle vine along irrigation line (15 cm apart). One tube was installed

One tube was installed directly under the dripper, near the measured middle vine, the second tube under the dripper between 2 vines and the last tube in the middle between these locations. Soil water content was measured every 6 - 8 days for one year at the same time with physiological measurements at different phenological stages, and more frequently during on long dry and wet periods.

Field calibration of the Diviner was performed by correlating probe readings with volumetric water content of soil samples as described in Groves and Rose (2004). The calibration equation for the capacitance probe was derived from regression analysis of sensor measurements of scale frequency (SF) against volumetric soil water content (θ_v) for each soil depth (10, 20, 30, 40, 50, 70 and 90 cm) with $SF = a\theta_v^b$. For calibration purposes, six probes were installed at the site covering a wide range of soil water contents following the procedure recommended by the manufacturer (Sentek, 2001; Polyakov *et al.*, 2005).

Soil samples to determine soil water content and bulk density were collected using a metal core with internal diameter of 50 mm for each depth. At the same time, the reading of the probe was logged 10 times to obtain the average scaled frequency. The relationship between capacitance probe reading and soil water content was good ($r^2 = 0.95, 0.93, 0.96$ and 0.83 for 10, 20 30 and 40 cm depth, respectively) only up to 40 cm depth whereas this relationship was poor at greater depth (in the clay horizon). Therefore only the water content up to 40 cm depth is presented.

A pressure plate apparatus was used to determine soil water content at matric suctions of - 10 kPa and - 1500 kPa, which represent water potential at field capacity (FC) and permanent wilting point (PWP), respectively (Cresswell, 2002; Or and Wraith, 2002). Total available water (TAW) at each soil 10 cm depth increment is as the difference between the soil water content at field capacity and permanent wilting point (Cassel and Dielsen, 1986).

Table 1. Basic physical and chemical properties of vineyard soil (clay loam) at 0 - 10, 10 - 20, 20 - 30 and 30 - 40 cm depth (n = 3).

Depth (cm)	Total organic carbon (g Kg ⁻¹)	Water content (gcm ⁻³)		TAW (g cm ⁻³)	Bulk density (g cm ⁻³)	Total porosity (%)	pH	EC (μS cm ⁻¹)
		FC	PWP					
0 - 10	17.0	0.42	0.09	0.32	1.4	47.4	5.8	48.6
10 - 20	10.7	0.40	0.10	0.31	1.4	45.7	5-9	40.0
20 - 30	9.0	0.41	0.11	0.30	1.5	42.0	6.0	43.3
30 - 40	8.9	0.42	0.14	0.28	1.6	39.2	6.1	51.1

FC is field capacity, PWP permanent wilting point, TAW total available water, EC electrical conductivity.

Gas exchange measurements

The photosynthetic rate (A , $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$), transpiration rate (E , $\text{mmol H}_2\text{O m}^{-2} \text{ s}^{-1}$) and stomatal conductance (g_s , $\text{mmol m}^{-2} \text{ s}^{-1}$) were determined between 11:00 and 14:00 on two mature leaves using a gas exchange system (LCA4, ADC BioScientific Ltd, UK) at different phenological stages starting nine months after compost application. Gas exchange per plant was calculated as gas exchange per leaf area unit multiplied by total leaf area index ($\text{m}^2 \text{ m}^{-2}$) of each vine.

Midday stem water potential (Ψ_s , MPa) was measured with a pressure chamber (1005 Pressure Chamber Instrument, PMS Instrument Company, USA) (Scholander *et al.*, 1965) at the same time as gas exchange measurements. Two mature, healthy and fully expanded leaves were selected from each plant and wrapped in plastic bags coated with aluminium foil for 20 min. Then, the stem was cut with a razor and inserted into the chamber within 30 seconds.

Plant growth measurements

Shoot length of three marked shoots per vine was measured every second week from budburst until end of November. After that date, shoot-length measurements were not continued because of abortion and shoot tip damage. When the berries had reached pea size, chlorophyll content of three leaves of each vine was measured with a portable meter (SPAD-502[®], Minolta, Japan). At harvest, all shoots were excised and the total number of chlorotic leaves counted.

Leaf area index (LAI) was measured weekly from budding until harvest (Ben-Asher *et al.*, 2006) by using a digital camera (Cyber-shoot, Sony, Japan) following the methodology proposed by Macfarlane *et al.* (2007) and analysed by a script developed by Fuentes *et al.* (2008a) on MATLAB[®] (The Mathworks Inc., Natick, MA, USA). The camera was set to automatic exposure to take upward digital images.

The following vine yield components were measured: number of bunches and berry per vine, number of berries per bunch, berry weight, dry berry weight taken from random 50 berries per vine, yield, rachis weight and specific berry weight (i.e. total berry weight per total berry number per vine). Berry quality attributes such as Brix, pH and titratable acidity were analysed after harvest. After leaf fall, pruning weights were recorded for each vine.

2.4. Statistical analysis

The experiment was designed in a randomized complete design with three compost treatments (control, incorporation and mulch) with 4 replicates. Analysis of variance (ANOVA) was applied; differences between means were compared by Duncan analysis ($p \leq 0.05$) using GenStat[®] 11th (GenStat[®] for Windows[®] 11th Edition, 2005). Data used for Principal Coordinates Analysis (PCoA) was yield, yield components (bunch number, berry number, berry number per bunch number, total berry weight, dry berry weight and specific berry weight), pruning weight, the number of chlorotic leaves and nutrient concentrations. This analysis is similar to principle component analyses (unconstrained ordination of multivariate data, projection-based), but PCoA allows much wider definition of dissimilarity and can use any chosen resemblance measure. Significant differences between treatments were determined by PERMANOVA (Primer-E Ltd, Plymouth Marine Laboratory, Plymouth, UK) based on 999 permutations

3. Results

3.1. Soil water content, gas exchange and stem water potential

Compared to the unamended control, mulched compost significantly increased soil water content only at 10 cm depth in dry and wet periods (Figure 1), and during the growing season (Figure 2), whereas incorporated

compost had no effect. The soil water content was two-fold higher in the wet period (0.3 g cm^{-3}) than in the dry period (0.15 g cm^{-3}). However, compost treatment did not affect soil water content in deeper soil layers in dry and wet periods (Figure 1) or during the growing season (data not shown). Furthermore, compost did not increase the total amount of water in the soil profile (data not shown). Compared to the unamended control, compost application did not affect transpiration rate, stomatal conductance (Figure 3B and 3C) or stem water potential (Table 2) at different phenological stages. The rate of photosynthesis per unit leaf area ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) was not affected by compost application, but mulched compost increased the photosynthesis per plant ($\mu\text{mol CO}_2 \text{ vine}^{-1} \text{ s}^{-1}$) at flowering, when the berries were pea-sized and at maturity (Figure 3A).

3.2. Growth, yield and leaf nutrient concentrations and berry quality

Mulched compost slightly, but not significantly increased shoot growth from day 56 (Figure 4A) and leaf area index from day 45, compared to the control and also to incorporated compost (Figure 4A). Compost addition did not significantly increase individual yield components such as bunch number, berry number, total berry weight per vine (Table 3), but increased dry berry weight, specific berry weight (Table 3), and pruning weight (Table 4), particularly mulched compost. Compost addition also increased chlorophyll concentration (Table 4). Compared to the unamended control, compost increased leaf N and P concentrations, particularly the mulched compost (Table 3) but had no effect on leaf K concentration (data not shown). Total soluble solids ($^{\circ}\text{Brix}$), pH and total acidity ($\text{g } 100 \text{ ml}^{-1}$) were 23.2, 3.6 and 4.1, respectively, with no significant differences between the unamended control and the compost treatments.

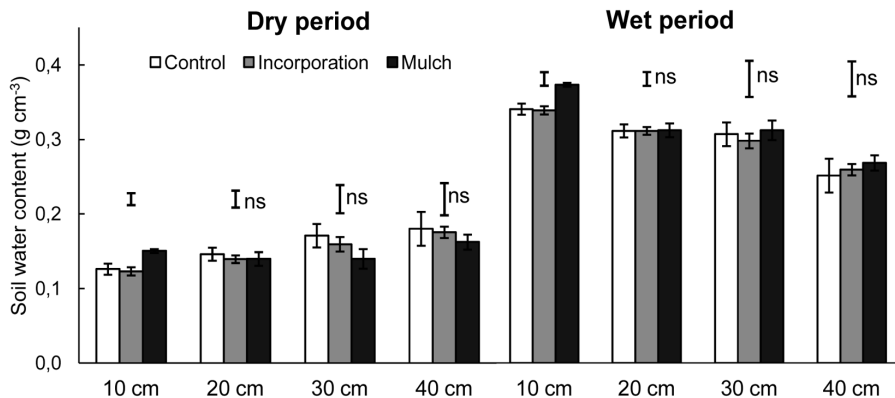


Figure 1. Soil water content (g cm^{-3}) in dry and wet periods at different depths (10, 20, 30 and 40 cm) in the unamended control or with incorporated or mulched compost ($n = 12 \pm$ standard error). Vertical lines are least significant difference. ns is not significant.

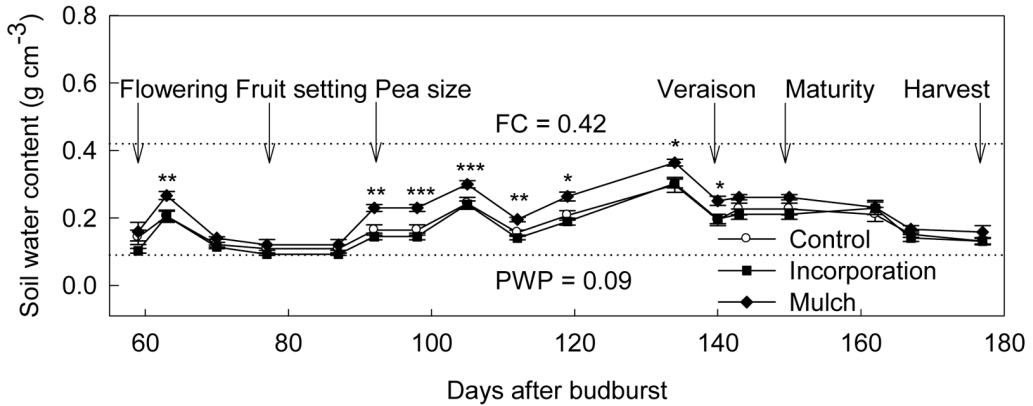


Figure 2. Soil water content throughout growing season for the unamended control (○) or with incorporated (■) and mulched (◆) compost at 10 cm depth (n = 12 ± standard error). The straight lines at the top and bottom of the graph represent the soil water content (g cm⁻³) at field capacity (FC) and permanent wilting point (PWP), respectively. * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

Table 2. Midday stem water potential at different phenological stages of vine in the unamended control or with incorporated or mulched compost. Values followed by the same letter are not significantly different (n = 4). ns is not significant.

Treatments	Midday stem water potential (MPa)					
	Flowering	Fruit setting	Pea size	Veraison	Maturity	Harvest
Control	- 0.53	- 0.75 ^a	- 0.58 ^a	- 1.05	- 1.18 ^a	- 1.02 ^{ab}
Incorporation	- 0.54	- 0.83 ^b	- 0.65 ^b	- 1.13	- 1.33 ^c	- 1.17 ^b
Mulch	- 0.51	- 0.79 ^{ab}	- 0.63 ^{ab}	- 1.09	- 1.22 ^b	- 1.09 ^a
LSD ($P \leq 0.05$)	ns	0.07	0.06	ns	0.07	0.06

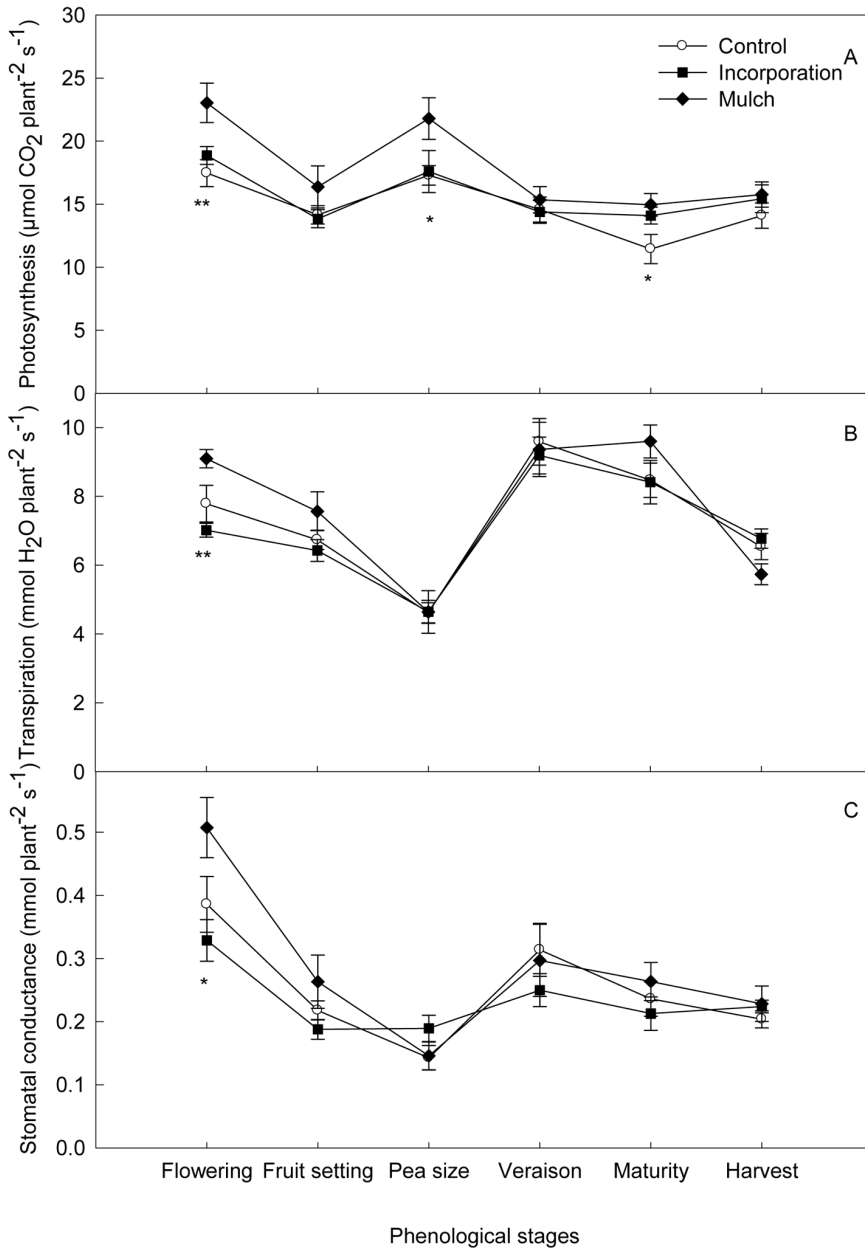


Figure 3. The rate of photosynthesis (A) and transpiration (B), and stomatal conductance (C) multiplied with leaf area index (LAI) values for unamended control (○) or with incorporated (■) and mulched (◆) compost at different phenological stages (n = 4 ± standard error). * $p \leq 0.05$, ** $p \leq 0.01$.

3.3. Multivariate analysis

The axes of the PCO plot explained 49.1% (PCO1) and 24.1% (PCO2) of the variability in the data (Figure 5). The plot showed a clear separation between the control and the compost treatments. Compared to the

unamended control, compost induced greater yield, specific berry weight, and leaf N concentration and reduced number of chlorotic leaves (Figure 5). The direction of the vectors indicates that yield, specific berry weight, and leaf N concentrations are positively correlated.

Table 3. Vine yield and yield components for cv. Merlot in the unamended control or with incorporated or mulched-compost. Values followed by the same letter are not significantly different (n = 4). ns is not significant.

Treatment	Bunches (No. vine ⁻¹)	Berry (No. vine ⁻¹)	Berry number per bunch	Berry weight (g vine ⁻¹)	Dry berry weight (g vine ⁻¹) ¹	Yield (g vine ⁻¹)	Rachis weight (g vine ⁻¹)	Specific berry weight (g No ⁻¹)
Control	57	2827	49	3555	18.6 ^a	3740	184.8	1.2 ^a
Incorporation	57	3260	57	4415	20.9 ^{ab}	4651	235.7	1.3 ^{ab}
Mulch	48	3076	61	4876	24.1 ^b	5110	233.9	1.4 ^b
LSD (P ≤ 0.05)	ns	ns	ns	ns	3.7	ns	ns	0.2

¹Data were obtained from fifty berries per ten bunches.

Table 4. Leaf nutrient concentrations, chlorophyll content, and pruning weight for cv. Merlot in the unamended control and plots with incorporated or mulched compost. Values followed by the same letter are not significantly different (n = 4).

Treatments	Leaf nutrient concentrations (g kg ⁻¹)		Chlorophyll ¹ (SPAD units)	Pruning weight (kg vine ⁻¹)
	N	P		
Control	15.3 ^a	0.9 ^a	34.1 ^a	0.55 ^a
Incorporation	18.3 ^b	1.1 ^{ab}	36.0 ^b	0.72 ^{ab}
Mulch	19.3 ^b	1.2 ^b	37.9 ^c	0.84 ^b
LSD (P ≤ 0.05)	2.4	0.2	1.7	0.24

¹The chlorophyll content was measured at pea size period (84 days after budburst).

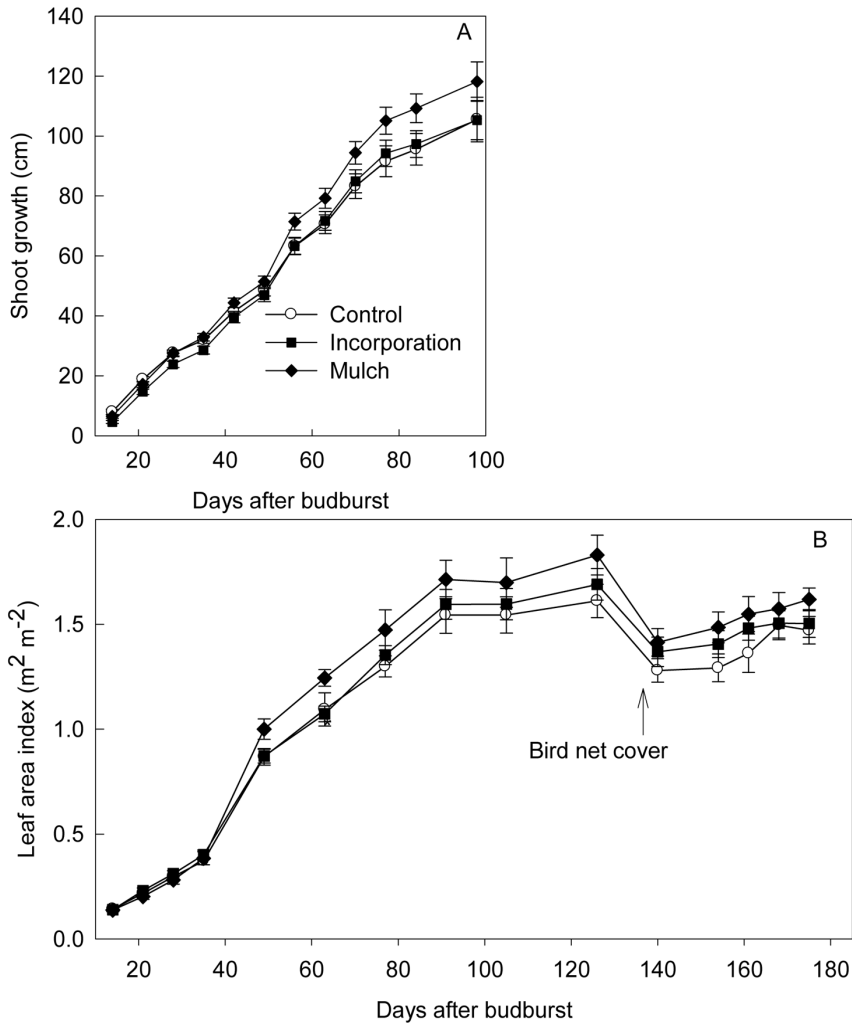


Figure 4. Shoot growth (A) and leaf area index (B) for the unamended control (○) or incorporated (■) and mulched (◆) compost during growing season (n = 4 ± standard error).

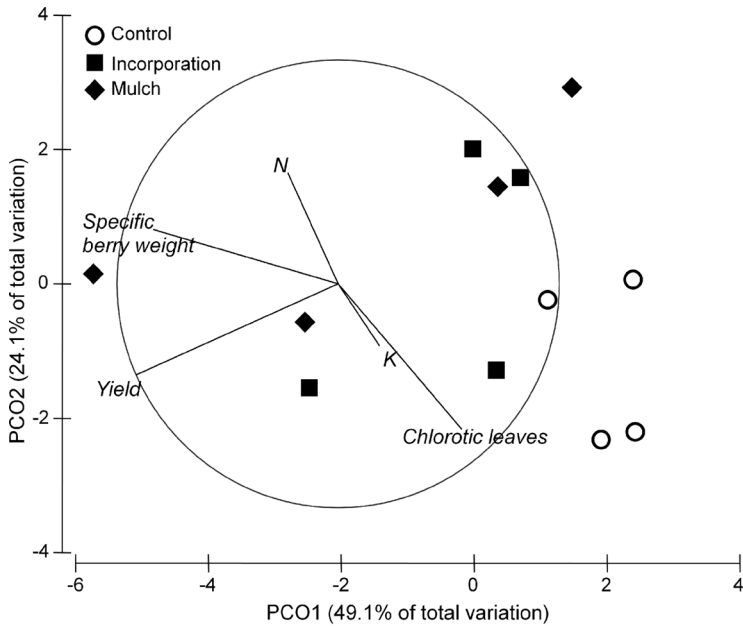


Figure 5. Principal co-ordinates analysis plot in unamended control vines (\circ) or with incorporated (\blacksquare) or mulched (\blacklozenge) compost. Vectors show parameters that explain $>5\%$ of the variance based on distance-based linear models (DistLM).

4. Discussion

Compost amendment was expected to increase soil water content, because mulched compost has been previously shown to reduce soil erosion by rain and runoff, and evaporation (Pinamonti, 1998). In the present study compared to the unamended control mulched compost increased soil water content only at 10 cm depth. This may be due to greater water holding capacity of compost and improved soil aggregation in the top soil by mulched compost (Celik *et al.*, 2004; Sodhi *et al.*, 2009). In addition, mulched compost can also reduce water loss by evaporation and drainage into deeper soil horizons (Pinamonti, 1998). The lack of significant effects of compost on soil water content in deeper soil layers may be due to the regular irrigation of the vineyard which avoided drying of the deeper soil layers. Most of the grapevine root biomass is below 30 cm depth (McKenry,

1984), therefore water uptake occurs mostly from deeper layers (Poni *et al.*, 1994) where in the present study the water content was similar in all treatments. This can explain why neither compost treatments affected transpiration rate and stomatal conductance (Figure 3B and 3C) or stem water potential (Table 2). The midday stem water potential (Table 2) indicated that grapevines were not water stressed from flowering until the berries had reached pea size (above -1.0 MPa), but they were moderately water stressed from veraison to harvest (below -1.0 MPa) (Acevedo-Opazo *et al.*, 2010). Mulched compost increased photosynthesis per plant ($\mu\text{mol CO}_2 \text{ plant}^{-1} \text{ s}^{-1}$) at flowering, when the berries were pea sized and at maturity (Figure 3A). This is due to the slightly higher leaf area index by mulched compost (Figure 4B), as mulching did not increase photosynthesis rate per cm^2 (data not shown).

Compost application can have considerable benefits for grapevine soil management, because it can supply organic matter and plant nutrients, improve soil properties and increase yield (Pinamonti, 1998; Biala, 2000). In the present study, the increase in growth and yield observed with compost amendment can be explained by the greater leaf nutrient concentrations (N and P), particularly with mulched compost (Table 3 and Figure 5). This may be due to an improved soil structure and thus nutrient accessibility (Pinamonti, 1998) and/or nutrients added with the compost (Biala, 2000). Moreover, the greater soil water content at 10 cm depth (Figures 1 and 2) may also have contributed to the greater yield and specific berry weight in compost treatments. Furthermore, compost has been shown to increase root density close to the soil surface (Pinamonti, 1998), which may aid uptake of nutrients released by compost (Fuentes *et al.*, 2008b). However, compost application did not affect grape quality attributes (data not shown). The results agree with previous findings by Pinamonti (1998) and Korboulewsky *et al.* (2004). Given the variable effect of compost on soil water content in the present study and the fact that the vines were irrigated it seems more likely that the positive effect of compost on vine growth and yield was due to the higher nutrient supply (Ussahatanonta *et al.*, 1996) which is corroborated by the Principal Co-ordinates plot where leaf N concentrations are positively correlated with yield and specific berry weight (Figure 5).

5. Conclusion

This study demonstrated that garden and food waste compost did not increase soil water content in the entire soil profile in the irrigated vines. However, mulched compost increased grapevine yield with no adverse effects on grape quality. The growth increase is most likely due to the increased nutrient supply from the compost. It can be concluded that compost can be an alternative source of nutrients for sustainable vineyard management.

Further research is required to investigate the long term effect of compost on grapevine physiology, growth, yield and quality under both well and water-stressed conditions.

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