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VITICULTURE ORIGINAL RESEARCH ARTICLES

Unravelling the interaction between the application of municipal solid waste compost and mechanical hedge pruning in vineyards: effects on the vegetative and reproductive growth, and grape and wine quality of Sauvignon from Lisbon wine region

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KEYWORDS:
hedge pruning, fertilization, unfolded canopy, organic amendments, sustainability, wine composition, sensory analysis

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ABSTRACT

In the last seven years, mechanical pruning has gained increasing relevance in Portugal, and alongside soil organic amendment, it contributes to the sustainable intensification of viticulture. The aim of this work was to study the interaction between increased bud load due to mechanical pruning and enhanced soil fertility due to progressive doses of municipal solid waste compost (MSWC), and their effects on reproductive and vegetative growth, as well as wine quality. A trial in a Sauvignon vineyard was implemented in the Lisbon wine region (Portugal). Mechanical hedge pruning was compared with hand spur pruning and the following four MSWC doses were applied for three consecutive years: 0 kg ha^{-1} year^{-1} (M0; control), 5000 kg ha^{-1} year^{-1} (M1), 10000 kg ha^{-1} year^{-1} (M2), and 20000 kg ha^{-1} year^{-1} (M3). Mechanical pruning significantly increased yield and reduced vine vigour and vegetative growth, whereas MSWC had no significant effect on yield, but showed a tendency for higher vigour and vegetative growth. Mechanical pruning increased not only yield, but also wine alcoholic strength. Both factors had some effects on wine colour, which were not perceived by the tasters. Although the tasters differentiated the wines from the different treatments in some parameters, no significant differences were found between treatments in global appreciation. The interaction between treatments was not significant in any of the analysed parameters. Although MSWC had no significant effects on yield or quality, its potential positive effects on soil fertility make it an interesting tool for enhancing vineyard sustainability, especially when combined with mechanical pruning.

INTRODUCTION

Pruning is one of the most critical viticultural practices to influence vine balance, canopy structure, yield and grape composition. Traditionally, pruning is performed by hand, representing a significant labour cost in vineyard management. Even with the introduction of pre-pruning and the use of assisted pruning shears, pruning represents about 30 % to 36 % of the hand labour required in a vineyard (Martinez-de-Toda & Sancha, 1999). The implementation of mechanised pruning systems has been shown to significantly increase grapevine yield (Lopes *et al*. 2000; Keller & Mills, 2007). Typically, this increase in production is not associated with a decline in grape quality (Gatti *et al*., 2011), except when yield exceeds the vine's productive capacity (Bovio & Lisa, 1996). In many cases, mechanised pruning may even contribute to improved grape quality (Clingeleffer, 2009).

Adaptation to mechanical pruning occurs when the yield increase resulting from a higher bud load is balanced by greater canopy efficiency (Poni *et al*., 2004). This balance can be achieved through the use of free growing canopies, which have higher overall photosynthetic rates compared with positioned canopies (Poni & Intrieri, 2001), if interrow width is maintained.

The application of municipal solid waste compost (MSWC) is a sustainable soil management strategy that enhances soil fertility, increases soil organic matter content and reduces the use of synthetic fertilisers (Diacono & Montemurro, 2010). Although MSWC has shown positive effects on vine performance (Messiga *et al*., 2015; Botelho *et al*., 2020a), the influence of different application rates on vegetative and reproductive growth, and grape and wine quality is not yet fully understood.

The application of organic amendments affects the chemical properties of soils, thus increasing the availability of nutrients (Illera-Vives *et al*., 2015; Botelho *et al*., 2021a), changing the nutrient status of the vine and affecting wine composition (Morlat & Symoneaux, 2008). In other studies, MSWC increased yield with no significant effects on wine colour and total phenols and only with slight differences in sensory analysis (Botelho *et al*., 2022).

Grapevines self-regulate the balance between the growth of roots, shoots and fruit (Keller, 2015). Mechanical pruning significantly increases bud load and as a consequence triggers self-regulation mechanisms that affect yield, namely a reduction in budburst (Botelho *et al*., 2020a), bud fertility (Byrne & Howell, 1978) and cluster weight (Christensen *et al*., 1994).

The objective of this study was to determine whether increasing soil fertility through progressive doses of MSWC can mitigate the impact of self-regulation mechanisms in mechanically pruned vines, thereby maintaining or enhancing vegetative and reproductive growth. Because yield and, in particular, leaf-to-fruit ratio influence grape and wine composition, this study also aims to assess the interactive effects of these two practices on grape and wine quality.

MATERIALS AND METHODS

1. Site description and experimental design

The experimental trial was carried out over four years (2018 to 2021) in a vineyard planted with *Vitis vinifera* L. cv. Sauvignon in Quinta do Gradil in the Lisbon wine region, Portugal. The vineyard, grafted on SO4, was planted in 2005 and spaced 1.0 m within the row and 2.6 m between rows (E) obtaining a density of 3846 plants/ha. Row orientation was NE–SW.

The soil in Quinta do Gradil was a Hypereutric Regosol (USS Working Group WRB, 2015), with a sandy-loam texture, a pH_{H2O} of 8.57, low organic matter content (1.32 %), and extractable K and P contents of 172.7 mg K/kg and 70.5 mg P/kg (ammonium lactate extraction – Egnér *et al.,* 1960), respectively. According to the multicriteria climatic classification system, proposed by Tonietto and Carbonneau (2004), Quinta do Gradil has a temperate viticultural climate (HI = –1), with cool nights (CI = +1), and is moderately dry (DI = +1) (Clímaco *et al*., 2012). Monthly total rainfall and mean air temperature data during the study are presented in Figure 1 (the available data begin in March 2019, because the weather station was not properly working before that).

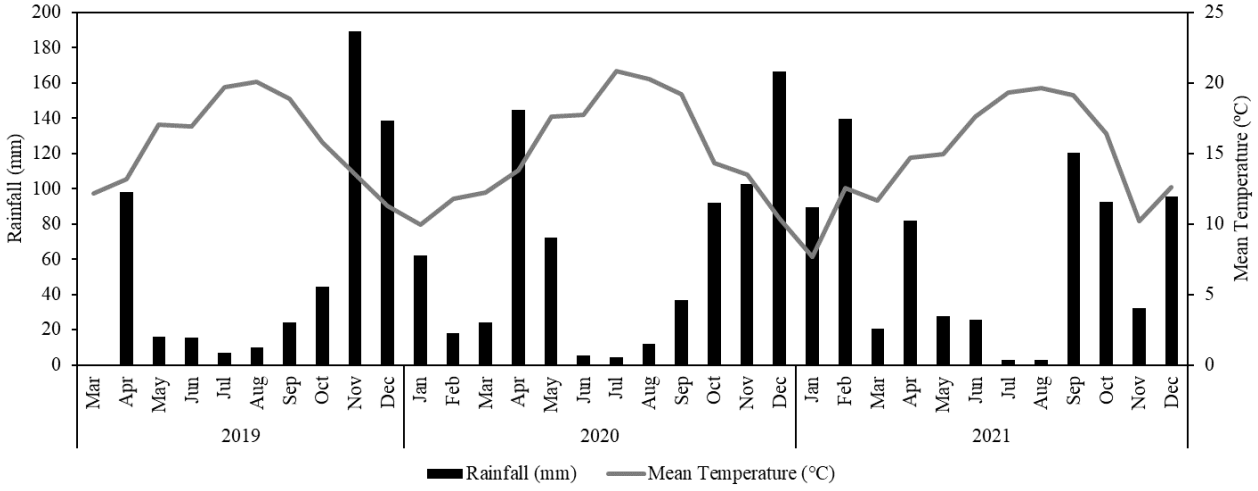


FIGURE 1. Monthly total rainfall and mean air temperature in Quinta do Gradil (Lisboa wine region, Portugal).

The studied factors were pruning system (hedge pruning and hand pruning) and municipal solid waste compost (MSWC) application doses, compared in a strip-plot design comprising four blocks. Each block contained six adjacent rows where pruning treatments were randomly applied, forming two groups of three adjacent lines each with a different pruning treatment. The 48-metre-long rows were equally divided into four (*i.e.*, each 12 m long), to which different MSWC doses were randomly applied. Each one of the 32 plots consisted of 36 vines.

Regarding pruning, two treatments were applied during the course of the experiment:

- manual spur pruning (MAN), retaining six to seven 2-bud spurs per vine;
- mechanical pruning (MEC), using a mechanical pruner (Pellenc TRP Precision Pruner) with 4 cutting disks (2 parallel and 2 perpendicular to the ground) and working at a distance of 15 cm from the cordon.

After pruning, a quick hand finishing was performed, spending 12 hours/ha to remove all wood with ventral insertion and to cut some canes next to the stakes. In the MAN treatment, the training system was a spur-pruned Royat cordon, established at 70 cm above the soil surface, with vertical shoot positioning (Figure 2 and Figure S1). Mobile wires were moved once in the season (just before bloom) in order to position the shoots, which were later trimmed to create a parallelepiped canopy. In the MEC treatment, the cordon was also established at 70 cm above soil surface and the wires were kept at the same position (20, 40, 60, and 80 cm above the cordon) the whole year. The shoots were not positioned; thus, some shoots attached themselves to the wire with their tendrils and grew vertically, while others grew freely in oblique or horizontal directions, creating a larger and sparser canopy (Figure 2 and Figure S1). In MEC, canopy management was limited to light and wide mechanical shoot trimming to promote upright growth and optimal machine operating conditions for harvest and the next winter pruning. Shoots were tipped to retain approximately 9 to 10 leaves on the main shoots.

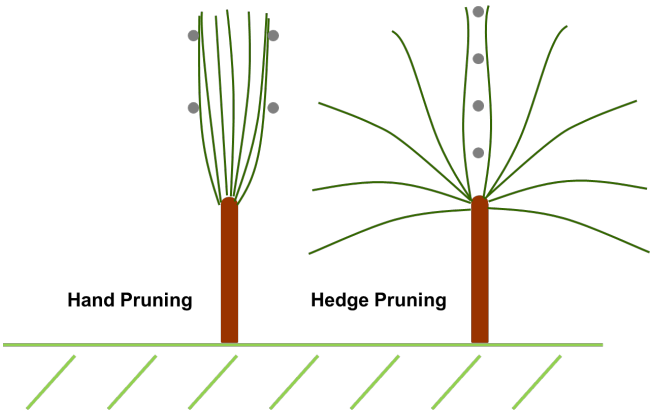


FIGURE 2. Canopy architecture of the two pruning systems.

Four organic amendment treatments were applied in 2018, 2019, and 2020: no MSWC (M0), 5,000 kg/ha/year of MSWC (M1), 10,000 kg/ha/year of MSWC (M2), and 20,000 kg/ha/year of MSWC (M3). Table 1 presents the average composition of MSWC. All treatments were supplemented with 40 kg/ha/year of nitrogen, according to the usual practice of the winegrower.

TABLE 1. Average composition of the organic amendments over the three years: biochar (BIOC), municipal solid waste compost (MSWC), cattle manure (Manure) and sewage sludge compost (Sludge).

	MSWC
fresh matter basis	
pH	7.90
Electrical conductivity (mS/m)	390.0
Moisture (%)	36.28
dry matter basis	
Organic matter (%)	37.3 ± 9.27
Total N (g kg^{-1})	10.03 ± 0.18
Total P (g kg^{-1})	5.63 ± 0.25
Total K (g kg^{-1})	7.85 ± 0.35
Total Ca (g kg^{-1})	75.39 ± 14.20
Total Mg (g kg^{-1})	14.94 ± 3.04
Total S (g kg^{-1})	4.52 ± 0.16
Total Na (g kg^{-1})	5.17 ± 2.65
Total Fe (g kg^{-1})	7.57 ± 0.07
Total Mn (mg kg^{-1})	304.10 ± 0.12
Total B (mg kg^{-1})	40.26 ± 0.83
Total Cu (mg kg^{-1})	183.77 ± 0.07
Total Zn (mg kg^{-1})	532.48 ± 0.03
Total Ni (mg kg^{-1})	20.89 ± 0.01
Total Cd (mg kg^{-1})	< 0.10 ± < 0.01
Total Pb (mg kg^{-1})	102.60 ± 0.06
Total Cr (mg kg^{-1})	40.49 ± 0.04

In each cell is presented the three years average ± standard deviation. When the standard deviation is lower than 0.01, the value is replaced by < 0.01.

2. Reproductive and vegetative growth

Exposed leaf area (ELA) and carbon balance were determined by the method proposed by Carbonneau (2026).

To determine yield components, the number of clusters per vine and their weight were assessed at harvest (18/09/2018, 10/09/2019, 10/09/2020, and 02/09/2021 for all treatments) in four previously selected vines in each experimental unit (128 vines total). During pruning, the number of canes per vine and their weight was measured in order to evaluate the effect of the different treatments on vegetative growth. The dry matter production was calculated as proposed by Carbonneau and Cargnello (2003): DMP = 0.2 * yield + 0.5 * pruning weight. The Ravaz Index was calculated by dividing the yield per vine by the dormant pruning weight of the same vine the following winter. The vines from which the pruning data were collected were the same as those evaluated at harvest.

3. Grape analysis

Before harvest, grapes were monitored to access their maturation stage and define harvest date. The parameters controlled in this phase were: one hundred berries weight (g), °Brix, potential alcohol content (% vol.), pH and total acidity (g tartaric acid/L).

4. Winemaking

When the grapes were at the ideal stage of maturation, manual harvest was performed on the same day for all treatments, and the grapes were transported to the experimental winery of Instituto Superior de Agronomia (Universidade de Lisboa), where they were destemmed, crushed, pressed, and fermented in 25-litre glass demijohns. Grapes from the four replicates per treatment were harvested for wine making. Forty kilograms of grapes were harvested per plot. In 2018, as MSWC was not yet expected to have any effect, only eight vinifications were carried out (two pruning systems × four blocks). In 2019 and 2020, thirty-two vinifications were performed to obtain a wine from each experimental unit (two pruning systems × four MSWC treatments × four blocks). In 2021, no vinifications were performed due to the cessation of funding.

Before pressing, 50 mg/kg of sulphur dioxide was added; one day after pressing, the must was clarified by static decanting, preceding the beginning of alcoholic fermentation. After decanting, the must was transferred to another bottle, where it was inoculated with a neutral yeast (Fermol® – AEB®) to start fermentation at cellar temperature (around 20 ºC). During fermentation, the temperature and density of the must were monitored daily.

Before bottling, free and total sulphur dioxide content were measured again, to correct all wines to 35 mg/L free SO_2 and the wines were stored in 750 mL bottles. After the bottling process, the wine was analysed for classical chemical parameters, chromatic characteristics, and phenolic composition, and a sensory analysis was performed.

5. Classical chemical parameters

The wine analysis was performed in the Enology Laboratory of Instituto Superior de Agronomia (Universidade de Lisboa).

Alcoholic strength by volume (distillation and densimetry), pH (potentiometry), total acidity (titration with sodium hydroxide with bromothymol blue as indicator), volatile acidity (steam distillation followed by acid-base titrimetry), total and free sulphur dioxide (by titration with iodine), and reducing substances (clarification with neutral lead acetate, reaction with alkaline copper salt solution and iodometry) in wines were analysed according to OIV described methods (OIV, 2021).

Malolactic fermentation did not occur. However, after alcoholic fermentation, paper chromatography was carried out to test for malolactic fermentation (Ribéreau-Gayon *et al*., 1982) and monitor the presence of malic and lactic acids in the wines. SO_2 levels were, in all cases, below the legal limit, while free SO_2 was maintained at a level of 35 mg/L.

6. Chromatic characteristics and phenolic compounds evaluation

Colour intensity, assessing the absorbency at 420 nm wavelength, was analysed according to the methods described by Singleton and Kramling, 1976.

Colour analysis was performed using the CIElab method that consists in the colorimetric characterisation (scanned from a range of 380 nm to 770 nm) of wines and other beverages by assigning them values in three different axis: the Luminosity axis (L*) ($0 < L^* < 100$, where 0 is black and 100 is the absence of colour), the a* axis, which evaluates colour according to its red/green component ($a^* > 0$ is red and, $a^* < 0$ is green) and the b* axis, which evaluates colour according to its blue/yellow component ($b^* > 0$ is yellow and $b^* < 0$ is blue). Chroma (C*) and Hue (H*) are derived from the numeric values for these three coordinates. Chroma is obtained using the equation $C^* = [(a^*)^2 + (b^*)^2]^{1/2}$, and hue, expressed in angle degrees, is calculated using $H^* = \tan^{-1} (b^*/a^*)$. After obtaining all the values described above, it is possible to compare two different colours through ΔE, which is obtained from the equation $\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$. According to Spagna *et al*. (1996), the human eye can distinguish two colours when ΔE is larger than two units; Mokrzycki and Tatol (2011), however, have found that while an experienced observer can distinguish between two colours when $2 < \Delta E < 1$, for an unexperienced observer this is only possible when $\Delta E > 2$.

Hue (H*), expressed in angle degrees (º), is typically considered to be the colour itself, as it translates the contributions of red, green, blue and yellow into a single colour. Chroma (C*) determines observed intensity for a specific value of hue, being the difference between the colour in question and a grey colour with the same luminosity (L*) value (Mokrzycki & Tatol, 2011).

The practical application of the method consists in centrifuging the wine for 10 min at 3500 rpm and then read its absorbency at several different wave lengths of between 380 nm and 780 nm (OIV, 2021).

The concentration of total phenolic compounds was determined from the absorbency at 280 nm. Regarding non-flavonoid compounds, flavonoid compounds were precipitated by causing a reaction with formaldehyde (Kramling & Singleton, 1969). The sample was then placed in the dark and incubated for 24 hours. The next day, the absorbance of the sample at 280 nm was read, and the value obtained reflected the concentration of the non-flavonoid compounds only. Thus, having determined the concentration of total phenolic compounds and non-flavonoid phenolic compounds, it was possible to deduce the concentration of flavonoid phenolic compounds.

7. Descriptive sensory analysis

Each wine sample was stored for 24 hours at room temperature before sensory analysis, which was performed at 20–22 °C in a sensory analysis room with individual booths for each expert, fluorescent light and tables with white surfaces (ISO 8589, 2007). All evaluations were conducted in the morning from 10:00 to 12:00. Eleven expert judges with wine tasting experience, most of them winemakers, evaluated the wine samples in two sensory evaluation sessions. In each session, wines were randomly divided into three flights, which were each tasted with a 20-min interval between them. Each wine was served in tasting glasses (ISO 3591, 1977) coded with a random three-digit code and filled with 25 mL of wine at a temperature of 18 ± 2 ºC. Wines were presented to the tasters in a random order. Water and crackers were used as palate cleaners.

All expert judges had been previously selected and trained for six months. This training period comprised several sessions in which the judges learnt the meaning of each attribute and how to apply intensity rating in a reliable way. The procedures for monitoring the performance of the panel are described in ISO 11132 (2012), and the practices are explained in the general guidelines for selecting, training and monitoring selected assessors and expert sensory assessors in ISO 8586 (2012).

The tasting of all 72 wines (8 from 2018, 32 from 2019 and 32 from 2020) was carried out on two separate days: the wines from 2018 and 2019 were tasted on 28 May 2021, and those from 2020 were tasted on 18 June 2021. The wines were separated into three different flights on each of these days: on the first day, the first flight comprised all the wines from 2018, the second consisted of blocks 1 and 2 and the third of blocks 3 and 4. On the second day, all three flights were made up of 11 wines each, with the wine from MAN/M3 block 2 being tasted twice; thus, the first flight comprised wines from blocks 1 and 2, the second wines from blocks 2 and 3 and the third wines from blocks 3 and 4.

Using a scale of 1 to 5, the tasters evaluated parameters related to the colour, aroma and taste of the wines. The sensory descriptors that were evaluated were those typically associated with the Sauvignon blanc variety.

The sensory attributes used were the following: colour ("yellow" and "green"), aroma ("fruit", "floral", "grapefruit", "passion fruit", "cat pee", "vegetal", "intensity" and "balance"), taste ("volume", "acidity", "persistency", "intensity" and "balance"), and "global appreciation".

The experts scored each sensory attribute based on the following 5-point scales:

- nonexistent (0), not very intense (1), moderately intense (2), intense (3), and very intense (4);
- mediocre (0), satisfactory (1), good (2), very good (3), excellent (4), this scale being used only for "balance" of aroma and taste, and "global appreciation".

8. Statistical Analysis

All data were tested to verify the assumptions of analysis of variance (ANOVA) using Shapiro-Wilk's test and then subjected to two-way (pruning x MSWC dosis) ANOVA, using the general linear procedure for strip-plot design and F test. The significance level was set at $\alpha = 0.05$ and means were separated using Tukey's honestly significant difference test. The statistical analysis was performed using Statistix software package (version 9.0; Analytical Software, Tallahassee, FL). Regression analysis was used to study the relationships between the continuous variables and the curves were fitted using the least squares method.

RESULTS

In Table 2, the productivity parameters results are presented. Mechanical pruning significantly increased the cluster number per vine over the four years of the trial. Although no differences in cluster weight between pruning systems were recorded, a slight tendency was observed in 2018 and 2020. In a global analysis, when compared to hand pruning, mechanical pruning significantly increased yield over the four years of the trial (28 %).

The application of MSWC to the vineyard had no effect on productivity parameters, even after a few years of application.

The effects of mechanical pruning and the soil organic amendment in terms of vigour and vegetative expression are presented in Table 3.

Regarding mechanical pruning, there was a tendency for higher shoot number per vine, which was significantly different in 2018 and 2020. By contrast, shoot weight was significantly lower for mechanical pruning. Finally, the pruning weight per vine was significantly lower for mechanical pruning in 2019 and 2021.

The application of MSWC had no significant effects on shoot number per vine or pruning weight per vine. Even in terms of shoot weight, the differences between organic amending treatments were significant in 2020 only, when M3 had significantly heavier shoots, compared to M0.

Table 4 presents the effects of the pruning system and the organic amendment on the balance between vegetative and reproductive growth (Ravaz Index), and on total dry matter production.

It is worth noting that the Ravaz Index is significantly lower in hand pruning than in mechanical pruning. Conversely, although dry matter production was not significantly affected by the pruning system, except in 2020, the results show a tendency for slightly higher values in mechanical pruning.

The soil organic amendment had no significant effects on the Ravaz Index or the total dry matter production. Moreover, when the results of each treatment over the years was compared, no consistent trend was observed.

The effects of the pruning system and MSWC doses on the physicochemical characteristics of the wine are presented in Table 5. Alcoholic strength was significantly higher in MEC

in 2018 and 2020, pH was not affected by the pruning system, total acidity was slightly lower in MEC in 2020 and volatile acidity was somewhat higher in MEC in 2018 and 2020.

Wine classical parameters were not significantly affected by MSWC application in any of the studied years.

The pruning system had no significant effects on the phenolic composition of the wines (Table 6). However, chromatic characteristics were somewhat affected by the pruning system. In 2019 and 2020, wine clarity was significantly different between pruning systems, though the differences were small and inconsistent. On the other hand, "a" and "b" tended to be higher in MAN, although the differences were significant only in one year (2018 for "a" and 2020 for "b"). The chroma values were tendentially higher in MAN, while hue was significantly higher in MEC in 2018.

Wines phenolic compositions and chromatic characteristics were not significantly affected by MSWC application to soil, except for hue in 2020 which was significantly higher in M0 than in M1.

Table 7 presents the results of the variation in colour (ΔE) and hue (ΔH) between the different treatments. The differences in colour were highest in 2020. No significant differences were observed between the MSWC treatments and, as in pruning system, ΔE was higher in 2020. When comparing the three years, ΔH was also highest in 2020, the values were tendentially higher between MSWC treatments than between pruning systems.

TABLE 2. Effect of pruning system and MSWC doses on cluster number per vine, cluster weight and yield.

Treatment	Clusters per vine				Cluster weight (g)				Yield (t/ha)			
	2018	2019	2020	2021	2018	2019	2020	2021	2018	2019	2020	2021
MAN	28.3 b	24.7 b	23.8 b	13.5 b	139	105	131	107	15.5	10.5 b	12.4 b	5.4 b
MEC	40.5 a	36.0 a	35.6 a	21.9 a	121	103	122	108	18.8	14.6 a	16.8 a	8.9 a
Sig.	*	***	*	*	n.s.	n.s.	n.s	n.s	n.s.	*	*	*
M0	33.8	31.7	28.4	18.3	130	110	135	106	16.7	13.5	13.9	7.3
M1	35.0	28.0	28.7	18.6	128	104	122	112	17.2	11.8	13.9	7.7
M2	33.9	30.4	32.6	17.5	131	104	126	110	16.9	12.9	16.5	7.5
M3	34.8	31.2	29.3	16.4	130	97	123	103	17.7	12.1	14.1	6.2
Sig.	n.s.	n.s.	n.s	n.s	n.s.	n.s.	n.s	n.s	n.s.	n.s.	n.s	n.s
Interaction	n.s.	n.s.	n.s	n.s	n.s.	n.s.	n.s	n.s	n.s.	n.s.	n.s	n.s

Statistical significance of the effects of pruning system, MSWC doses and their interactions: n.s. = not significant at the 5 % level by F test; *, **, *** mean significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. Within each column and for each factor, mean values followed by a different letter are significantly different at $p < 0.05$ by Tukey's test.

Pruning system: hand pruning (MAN) and mechanical pruning (MEC). Organic amendments: control (M0), 5 t/ha/year of MSWC (M1), 10 t/ha/year of MSWC (M2), 20 t/ha/year of MSWC (M3).

TABLE 3. Effect of pruning system and MSWC doses on shoot number per vine, shoot weight and pruning weight per vine.

Treatment	Shoots per vine				Shoot weight (g)				Pruning weight (g/vine)			
	2018	2019	2020	2021	2018	2019	2020	2021	2018	2019	2020	2021
MAN	20.4	20.4	19.6 b	23.2	57.0	53.2 a	56.3 a	54.8 a	1,140	1,072 a	1,072	1,250 a
MEC	25.2	23.2	26.6 a	27.9	37.2	30.7 b	35.2 b	35.6 b	877	698 b	897	961 b
Sig.	*	n.s.	*	n.s	*	**	*	**	n.s.	**	n.s	*
M0	22.1	22.0	24.1	25.5	56.0	36.6	38.7 b	45.0	1,215	769	852	1,073
M1	23.1	22.0	22.7	26.5	43.1	40.6	45.4 ab	45.4	894	861	953	1,132
M2	22.6	21.9	23.3	25.2	45.7	40.8	44.0 ab	43.5	965	879	940	1,042
M3	23.6	21.2	22.3	25.1	43.6	49.8	54.9 a	47.0	960	1,031	1,192	1,175
Sig.	n.s.	n.s.	n.s	n.s	n.s.	n.s	*	n.s	n.s.	n.s	n.s	n.s
Interaction	n.s.	n.s.	n.s	n.s	n.s.	n.s	n.s	n.s	n.s.	n.s	n.s	n.s

Statistical significance of the effects of pruning system, MSWC doses and their interactions: n.s. = not significant at the 5 % level by F test; *, **, *** mean significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. Within each column and for each factor, mean values followed by a different letter are significantly different at $p < 0.05$ by Tukey's test.

Pruning system: hand pruning (MAN) and mechanical pruning (MEC). Organic amendments: control (M0), 5 t/ha/year of MSWC (M1), 10 t/ha/year of MSWC (M2), 20 t/ha/year of MSWC (M3).

TABLE 4. Effect of pruning system and MSWC doses on the Ravaz Index and dry matter production.

Treatment	Ravaz Index				Dry matter production (t/ha)			
	2018	2019	2020	2021	2018	2019	2020	2021
MAN	4.31	2.82 b	3.28 b	1.19 b	5.29	4.17	4.54 b	3.48
MEC	6.12	5.75 a	5.55 a	2.47 a	5.45	4.26	5.09 a	3.62
Sig.	*	***	*	**	n.s.	n.s.	*	n.s
M0	4.66	5.09	4.63	1.83	5.68	4.18	4.42	3.52
M1	5.56	3.96	4.06	1.91	5.16	4.01	4.61	3.71
M2	5.07	4.38	5.03	2.03	5.23	4.26	5.11	3.50
M3	5.59	3.73	3.94	1.54	5.39	4.41	5.11	3.49
Sig.	n.s.	n.s	n.s	n.s	n.s.	n.s.	n.s	n.s
Interaction	n.s.	n.s	n.s	n.s	n.s.	n.s.	n.s	n.s

Statistical significance of the effects of pruning system, MSWC doses and their interactions: n.s. = not significant at the 5 % level by F test; *, **, *** mean significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. Within each column and for each factor, mean values followed by a different letter are significantly different at $p < 0.05$ by Tukey's test.

Pruning system: hand pruning (MAN) and mechanical pruning (MEC). Organic amendments: control (M0), 5 t/ha/year of MSWC (M1), 10 t/ha/year of MSWC (M2), 20 t/ha/year of MSWC (M3).

TABLE 5. Effect of pruning system and MSWC doses on physicochemical characteristics (classical parameters) of wine.

Treatment	Alcoholic strength (%vol.)	pH	Total acidity (g/L)a	Volatile acidity (g/L)b	Reducing substances (g/L)
2018					
MAN	13.0 b	3.15	8.87	0.35 b	0.38
MEC	13.5 a	3.15	8.47	0.49 a	0.40
Sig.	*	n.s.	n.s.	*	n.s.
2019					
MAN	14.4	3.27	8.98	0.46	1.09
MEC	14.6	3.25	8.52	0.49	0.83
Sig.	n.s.	n.s.	n.s.	n.s.	n.s.
M0	14.4	3.25	8.92	0.47	0.82
M1	14.7	3.28	8.43	0.51	0.91
M2	14.5	3.26	8.77	0.48	1.18
M3	14.6	3.26	8.88	0.44	0.93
Sig.	n.s.	n.s.	n.s.	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.
2020					
MAN	13.1 b	3.04	8.96 a	0.45 b	0.76
MEC	13.5 a	3.05	8.23 b	0.57 a	0.75
Sig.	**	n.s.	*	**	n.s.
M0	13.3	3.02	8.87	0.46	0.82
M1	13.3	3.06	8.34	0.53	0.64
M2	13.2	3.05	8.76	0.51	0.77
M3	13.4	3.06	8.42	0.53	0.80
Sig.	n.s.	n.s.	n.s.	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.

[a] Expressed in tartaric acid.

[b] Expressed in acetic acid.

Statistical significance of the effects of pruning system, MSWC doses and their interactions: n.s. = not significant at the 5 % level by F test; *, **, *** mean significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. Within each column and for each factor, mean values followed by a different letter are significantly different at $p < 0.05$ by Tukey's test.

Pruning system: hand pruning (MAN) and mechanical pruning (MEC). Organic amendments: control (M0), 5 t/ha/year of MSWC (M1), 10 t/ha/year of MSWC (M2), 20 t/ha/year of MSWC (M3).

TABLE 6. Effect of pruning system and MSWC doses on phenolic composition and chromatic characteristics of the wines.

Treatment	Total phenolsa	Non flavonoidsa	Flavonoidsa	Absorbance 420 nm	Clarity	a	b	Chroma	Hue
				2018					
MAN	166.3	87.1	79.2	0.084	99.2	–0.43 b	2.99	3.02	81.9 b
MEC	173.1	89.6	83.5	0.085	99.3	–0.27 a	2.76	2.77	84.4 a
Sig.	n.s.	n.s.	n.s.	n.s.	n.s.	**	n.s.	n.s.	**
				2019					
MAN	180.3	65.5	114.8	0.100 a	98.5 b	–0.34	3.56	3.69	84.35
MEC	188.6	66.1	122.5	0.093 b	98.8 a	–0.26	3.43	3.44	85.73
Sig.	n.s.	n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.	n.s.
M0	185.9	64.9	120.9	0.094	98.7	–0.33	3.41	3.43	84.31
M1	180.0	65.3	114.6	0.100	98.6	–0.25	3.48	3.49	85.85
M2	187.2	65.7	121.4	0.100	98.8	–0.31	3.49	3.5	85.05
M3	184.8	67.2	117.6	0.100	98.6	–0.32	3.60	3.64	84.95
Sig.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
				2020					
MAN	176.4	68.5	108.0	0.063	99.6 a	–0.12	4.92 a	4.93 a	88.31
MEC	177.6	68.1	109.6	0.063	99.0 b	–0.12	4.30 b	4.30 b	88.03
Sig.	n.s.	n.s.	n.s.	n.s.	**	n.s.	**	**	n.s.
M0	177.8	69.0	108.8	0.063	99.3	–0.06	4.66	4.66	89.06 a
M1	178.1	68.1	110.1	0.063	99.3	–0.16	4.66	4.66	87.54 b
M2	172.2	66.0	106.2	0.061	99.5	–0.14	4.47	4.47	88.18 ab
M3	180.0	70.0	110.0	0.065	99.2	–0.12	4.66	4.66	87.89 ab
Sig.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

[a] Expressed in mg of gallic acid per liter.

Statistical significance of the effects of pruning system, MSWC doses their interactions: n.s. = not significant at the 5 % level by F test; *, **, *** mean significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. Within each column and for each factor, mean values followed by a different letter are significantly different at $p < 0.05$ by Tukey's test.

Pruning system: hand pruning (MAN) and mechanical pruning (MEC). Organic amendments: control (M0), 5 t/ha/year of MSWC (M1), 10 t/ha/year of MSWC (M2), 20 t/ha/year of MSWC (M3). a) red-green contribution to wine colour; b) yellow-blue contribution to wine colour.

TABLE 7. Effect of the pruning system and MSWC doses on the variation in colour (ΔE) hue (ΔH).

	ΔE			ΔH		
	2018	2019	2020	2018	2019	2020
MAN/MEC	0.35	0.58	1.56	0.11	0.22	0.94
	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
M0/M1		0.74	1.82		0.08	1.68
M0/M2		0.44	1.14		0.04	0.89
M0/M3		0.55	1.65		0.09	1.42
M1/M2		0.38	1.21		0.06	1.13
M1/M3		0.59	1.91		0.10	0.94
M2/M3		0.38	1.33		0.07	1.12
		n.s.	n.s.		n.s.	n.s.

Statistical significance of the effects of pruning system, MSWC doses and their interactions: n.a. = not applicable, n.s. = not significant at the 5 % level by F test.

Pruning system: hand pruning (MAN) and mechanical pruning (MEC). Organic amendments: control (M0), 5 t/ha/year of MSWC (M1), 10 t/ha/year of MSWC (M2), 20 t/ha/year of MSWC (M3).

The results of the sensorial analysis, namely those related to visual and olfactory characterisation, are presented in Table 8.

In terms of visual attributes, the wines of 2018 and 2019 were greener, showing a more youthful colour than those from 2020, whose colour was characterised by the tasters as tending towards yellow rather than green. The studied treatments had no significant effects on the visual aspects of the wines in any year of the trial.

In terms of olfactory aspects, mechanical pruning resulted in some significant differences in 2018 and 2019, but not in 2020: the 2018 wines from MEC had less intense cat pee and vegetal aromas, while the 2019 wines had lower aroma intensity and balance. However, from a practical point of view, the observed differences were negligible (equal to or less than 4.9 %), despite being statistically significant.

In terms of the effects of soil organic amendment on wine aroma, significant differences between treatments were observed only in 2019. Wines from M3 showed more intense aromas than those from M0 and M1, and fruitier aromas than M0.

Data regarding the wine gustatory attributes and overall appreciation are presented in Table 9. Mechanical pruning had a few but mostly negligible effects on wine in the mouth sensorial analysis. Only in 2019 was the acidity somewhat lower in MEC (1.8 %) and in 2020 the taste intensity was also slightly lower in MEC (2.7 %).

Except for wine body, soil organic amendment had no effects on taster palate perception in 2019. Wines from M3 and M1 had significantly more body than M0 in 2019, but the difference was not substantial (6.3 % and 6.6 % respectively).

DISCUSSION

The effects of mechanical pruning on cluster number per vine (Table 2) are positive, with a significant increase in this variable every year of the trial. These results are consistent with the literature (Barcia *et al*., 2023; Allegro *et al*., 2022; Botelho *et al*., 2020a) and are due to the higher bud number per plant which, in spite of the lower budburst percentage, leads to

TABLE 8. Effect of pruning system and MSWC doses on visual and olfactory attributes in the wine sensory analysis.

Treatment	Yellow	Green	Aroma intensity	Aroma balance	Fruity	Floral	Grape-fruit	Passion fruit	Cat pee	Vegetal
2018										
MAN	1.86	2.57	2.98	2.91	2.45	1.75	1.89	1.70	1.64 a	2.66 a
MEC	1.95	2.59	2.72	2.65	2.36	1.86	1.84	1.61	1.30 b	2.11 b
Sig.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*	**
2019										
MAN	2.03	2.56	2.86 a	2.86 a	2.29	1.95	1.73	1.76	1.58	2.56
MEC	2.01	2.58	2.72 b	2.70 b	2.27	1.92	1.69	1.61	1.49	2.57
Sig.	n.s.	n.s.	**	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
M0	2.04	2.57	2.74	2.71 b	2.07 b	1.96	1.64	1.67	1.56	2.53
M1	2.01	2.56	2.78	2.71 b	2.32 ab	1.96	1.63	1.58	1.53	2.57
M2	1.96	2.57	2.81	2.72 ab	2.26 ab	1.94	1.74	1.69	1.58	2.64
M3	2.06	2.60	2.83	2.99 a	2.47 a	1.89	1.85	1.81	1.46	2.53
Sig.	n.s.	n.s.	n.s.	*	*	n.s.	n.s.	n.s.	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
2020										
MAN	2.51	2.17	3.24	2.99	3.05	1.90	2.44	2.07	1.63	2.28
MEC	2.46	2.16	3.04	3.03	2.99	1.91	2.52	2.04	1.49	2.17
Sig.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
M0	2.52	2.16	3.21	3.11	3.07	1.97	2.43	2.14	1.59	2.23
M1	2.50	2.16	3.14	2.95	2.94	1.89	2.56	2.05	1.52	2.32
M2	2.43	2.18	3.16	3.01	3.10	1.97	2.46	1.99	1.51	2.18
M3	2.50	2.16	3.05	2.98	2.97	1.78	2.48	2.04	1.63	2.17
Sig.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Statistical significance of the effects of pruning system, MSWC doses their interactions: n.s. = not significant at the 5 % level by F test; *, **, *** mean significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. Within each column and for each factor, mean values followed by a different letter are significantly different at $p < 0.05$ by Tukey's test.

Pruning system: hand pruning (MAN) and mechanical pruning (MEC). Organic amendments: control (M0), 5 t/ha/year of MSWC (M1), 10 t/ha/year of MSWC (M2), 20 t/ha/year of MSWC (M3).

TABLE 9. Effect of pruning system and MSWC doses on gustatory attributes and overall appreciation of wines sensory analysis.

	Taste intensity	Taste balance	Acidity	Body	Persistence	Overall appreciation
			2018			
MAN	3.09	2.95	3.34	2.63	2.93	3.05
MEC	2.95	2.86	3.34	2.45	2.95	2.90
Sig.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
			2019			
MAN	3.06	2.88	3.39	2.66	2.97	2.93
MEC	2.98	2.82	3.33	2.67	2.90	2.77
Sig.	n.s.	n.s.	*	n.s.	n.s.	n.s.
M0	2.92	2.76	3.38	2.54 b	2.81	2.76 b
M1	3.00	2.88	3.35	2.72 a	3.00	2.84 ab
M2	3.01	2.90	3.31	2.69 ab	3.01	2.92 a
M3	3.15	2.84	3.38	2.71 a	2.90	2.88 ab
Sig.	n.s.	n.s.	n.s.	*	n.s.	*
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
			2020			
MAN	3.35	3.01	3.50	2.75	2.91	3.07
MEC	3.26	2.99	3.46	2.79	2.86	3.05
Sig.	*	n.s.	n.s.	n.s.	n.s.	n.s.
M0	3.37	3.05	3.39	2.79	2.92	3.13
M1	3.27	3.02	3.52	2.79	2.86	2.98
M2	3.31	2.97	3.51	2.68	2.88	3.05
M3	3.29	2.98	3.48	2.82	2.87	3.08
Sig.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Interaction	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Statistical significance of the effects of pruning system, MSWC doses their interactions: n.s. = not significant at the 5 % level by F test; *, **, *** mean significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively. Within each column and for each factor, mean values followed by a different letter are significantly different at $p < 0.05$ by Tukey's test.

Pruning system: hand pruning (MAN) and mechanical pruning (MEC). Organic amendments: control (M0), 5 t/ha/year of MSWC (M1), 10 t/ha/year of MSWC (M2), 20 t/ha/year of MSWC (M3).

a higher shoot number and, thus, higher cluster number per plant (Martinez-de-Toda & Sancha, 1999; Geller & Kurtural, 2013). Additionally, in MAN there is usually a higher proportion of water shoots than in MEC (Botelho *et al.*, 2020a), which are less fruitful shoots (Champagnol, 1984) that produce smaller clusters (Wolpert *et al.*, 1983).

The pruning system had no significant effect on cluster weight in any of the assessed years, although a tendency for lighter clusters in MEC was observed in 2018 and 2020. While most studies have found mechanical pruning to result in significantly lighter clusters (Martinez-de-Toda & Sancha, 1999; Poni *et al.*, 2004; Geller & Kurtural, 2013), some have not found any differences in cluster weight (Barcia *et al.*, 2023). Regarding canopy architecture, MEC is an unfolded canopy (Carbonneau & Cargnello, 2003), while MAN is vertical shoot position trained and free canopies are known to have higher light interception within the canopy (Botelho *et al.*, 2020a) and, consequently, a higher overall net photosynthesis than vertical shoot positioned canopies (Intrieri *et al.*, 1997). Moreover, the present trial was carried out on flat terrain in a valley, and with minimal water restriction. Thus, despite the higher cluster number per vine, MEC vines compensated for the cluster weight and no differences were recorded, probably due to canopy architecture and sufficient water supply.

Although no significant differences were recorded in 2018, overall yield was significantly higher in MEC. This has been observed by several other authors (Lopes *et al.*, 2000; Keller & Mills, 2007; Allegro *et al*., 2022) and is the result of the higher cluster number per vine, which was not compensated for a significant decrease in cluster weight.

The soil organic amendment had no significant effect on yield components, which is consistent with the results reported by Pinamonti (1998) but contrasts with the findings of Messiga *et al*. (2015) and Botelho *et al.* (2020a). In particular Botelho *et al*. (2020a) observed an increase in yield with the application of 16,100 kg/ha/year, which is due to the higher number of clusters per vine. However, in the present study, all treatments underwent fertilisation (40 kg N ha^{-1}), which may have overshadowed the effect of the MSWC. According to the literature, because MSWC is composted, N mineralisation rate is less than 15 % (ranging from 5 % to 15 %) of the total N supplied by the compost, followed by an annual release of 2 % to 8 % of the remaining compost-N in subsequent years (Amlinger *et al.*, 2003). Therefore, the primary N source during the trial was the inorganic fertiliser, which was applied uniformly across all treatments. The nitrogen rate application that maximises yield is between 30 and 40 kg N ha^{-1} (Visconti *et al*., 2023) which is the nitrogen application rate provided by the applied fertiliser. Since nitrogen is a key nutrient for both the vegetative and reproductive growth of vines, and is the limiting nutrient in this case, as phosphorus and potassium levels in the soil were adequate (Soveral-Dias *et al.*, 1980), no differences were observed between the various MSWC doses.

The shoot number per vine was tendentially higher in MEC, as observed by other authors (Clingeleffer & Krake, 1992; Bovio & Lisa, 1996). This increase in shoot number per vine is due to the increase in bud load (Clingeleffer & Krake, 1992) which, despite a lower budburst percentage (Botelho *et al.*, 2020a), still gives rise to a higher shoot number.

Shoot weight and pruning weight per vine were significantly lower in MEC, as reported by other authors (Martinez-de-Toda & Sancha, 1999; Botelho *et al.*, 2020a). The decrease in these variables is related to the increase in shoot number that reduces the individual growth of each shoot (Botelho *et al.*, 2012) and to the increase in reproductive growth that competes for assimilates with vegetative growth and, consequently, reduces total pruning weight per vine (Edson *et al.*, 1993).

Regarding the effect of MSWC on vegetative growth parameters, no significant differences were observed, except for shoot weight in 2020, when M3 shoots were significantly heavier than M0. In contrast to the results of Botelho *et al.* (2020a), who reported an increase in shoot number, shoot weight and total pruning weight after three years of MSWC application, the present study showed minimal significant effects. However, in the aforementioned study, none of the treatments were supplemented with inorganic fertilisers to provide nitrogen. As a result, the only nutrient source was the organic amendment, leading to significant differences between the control and amended treatments. In contrast, in the present study, all treatments underwent an annual nitrogen fertilisation of 40 kg/ha. Given the low mineralisation rate of MSWC, the nitrogen supply across treatments remained similar, which likely explains the absence of significant differences in vegetative growth parameters.

Mechanical pruning significantly increased the Ravaz Index throughout the trial. Similar results have been reported by other authors (Botelho *et al.*, 2020a), who attributed this increase to a higher yield and a reduction in pruning weight. However, the observed values remain below the optimal range of 6 to 10, as proposed by Smart *et al.* (1990), indicating low yields and excessive shoot vigour. Nevertheless, the higher Ravaz Index values in MEC treatments are closer to the ideal range compared to MAN, suggesting a better balance between vegetative and reproductive growth.

Although the differences were significant in 2020 only, the effect of mechanical pruning on total dry matter production was tendentially positive. This result is in accordance with other authors (Martinez-de-Toda & Sancha, 1999; Botelho *et al.*, 2020b) and is probably the consequence of the different canopy architecture between pruning systems. In fact, free canopies have a better light microclimate in the canopy (Botelho *et al.*, 2020a). As a consequence, free canopies achieve higher global net photosynthesis and higher assimilate production than vertical shoot positioned canopies (Intrieri *et al.*, 1997).

Soil organic amendment had no significant effect on either the Ravaz Index or total dry matter production. The absence of differences in the Ravaz Index, previously reported by other authors (Botelho *et al.*, 2020a), is likely due to the lack of variation in yield or pruning weight across MSWC doses. The lack of differences in dry matter production is probably related to the similar nitrogen supply between treatments, as dry matter production in non-restrictive light conditions is positively correlated with nitrogen supply (Keller & Koblet, 1995).

The analysis of alcoholic strength revealed a significantly higher value in MEC, which contradicts the findings of Holt *et al.* (2008) and Botelho *et al.* (2021b). These authors reported lower sugar accumulation in mechanically pruned systems, leading to wines with lower alcoholic strength. They attributed this reduction in sugar content to delayed maturation, which is associated with increased production due to the higher bud load.

MEC had tendentially higher values of ELA (Table S1) in three out of four years, revealing a higher photosynthetic potential. Moreover, the carbon balance, calculated according to Carbonneau (2026), indicates a tendency towards a higher carbon availability for grapes in MEC (Carbonneau & Torregrosa, 2020). In fact, the higher ELA, which is associated with lower vigour in the mechanically pruned treatment, results in a higher carbon balance and in turn to grapes with higher sugar content (Carbonneau & Torregrosa, 2020).

Moreover, although ELA did not significantly differ between pruning systems, the canopy architecture in MEC led to a less dense canopy, with higher light interception inside the canopy (Table S1). Since the increase in PAR inside the canopy was within the range where the increase in photosynthetic rate was higher (Rogiers & Clarke, 2013), it can be concluded that a higher proportion of leaves was photosynthesising at high rates in MEC at any given time, and the overall canopy photosynthetic rate in MEC was higher than in MAN, as reported by Intrieri *et al.* (1997).

In fact, Intrieri *et al.* (1997) reported a 26 % increase in overall plant photosynthesis in free-growing canopies compared to positioned ones, as a greater proportion of leaves are exposed to sunlight at any given time. Moreover, in free-growing canopies, leaves alternate rapidly between light and shade, leading to higher photosynthetic efficiency (Poni & Intrieri, 2001). This increase in overall plant photosynthesis likely compensated for the higher yield, as total leaf area per plant typically remains similar between hand and mechanical pruning (Botelho *et al.*, 2020a).

Although free canopies have a higher plant overall photosynthetic rate, they require a higher interrow width than VSP, allowing the use of machinery in the vineyard. Since VSP can work with lower interrow widths, the system may compensate for the lower canopy efficiency by narrowing interrow. However, in the present case, the interrow width was the same in both pruning systems, thus the MEC system had a higher photosynthetic rate per hectare, leading to higher overall sugar production and, consequently, to wines with higher alcoholic strength.

The application of MSWC did not affect wine alcoholic strength, as already reported by previous studies (Mugnai *et al.,* 2012; Botelho *et al*., 2022), and is probably related to the lack of differences in yield between treatments.

Wine pH was not significantly affected by any of the factors studied. This is consistent with previous findings, where no significant differences in pH were reported in response to mechanical pruning (Keller & Mills, 2007; Allegro *et al*., 2022). Although pH differences are often associated with delayed ripening (Conde *et al.*, 2007) (a common outcome of mechanical pruning (Botelho *et al.*, 2021b; Botelho *et al*., 2022)), such a delay was not observed in the present study.

Total acidity was tendentially lower in MEC, although the differences were not important from a technical point of view. Several other authors have found no differences in total acidity with mechanical pruning (Holt *et al*., 2008; Kurtural *et al*., 2019), despite an occasional tendency for a delay in ripening that leads to higher acidities (Clingeleffer & Krake, 1992). Concerning MSWC effects on total acidity, no differences were found between the different doses, as observed in other studies (Mugnai *et al.*, 2012; Botelho *et al*., 2020c; Botelho *et al*., 2021b; Cataldo *et al*., 2022).

The impact of MEC on wine alcoholic strength (slight increase) and total acidity (slight decrease) are not in line with new market trends, which favour wines with less alcohol. However, in the present study the harvest of all treatments was performed on the same day; therefore, if the harvest of MEC had been performed earlier, the wines may have had lower alcoholic strength and higher acidity. An earlier harvest is of particular interest in the Lisbon wine region to potentially prevent *Botrytis cinerea* infections, since late September rain is common. Concerning the incidence of fungal diseases in vineyard, although MEC increases shoot density (Table 3), the different canopy architecture leads to a lower leaf area density and, consequently, to a higher sunlight penetration within the canopy (Table S1); this lower canopy density reduces fungal disease infections, such as powdery mildew (Austin *et al*., 2011). Moreover, the higher number of clusters in MEC lead to less compact clusters, that are less prone to *Botrytis cinerea* infections (Schäfer *et al*., 2021).

From a social point of view, mechanical pruning helps to solve the lack of specialised hand-labour for pruning, which is an emerging problem that concerns most winegrowers.

Total phenols, as well as flavonoids and non-flavonoids, were not significantly affected by either pruning or MSWC. The lack of influence of mechanical pruning on phenolic composition is consistent with the results obtained by other authors (Pérez-Bermúdez *et al*., 2015; Botelho *et al*., 2022). No MSWC effects on phenolic composition were observed, as has been reported in the literature (Cataldo *et al*., 2022). Some studies have reported a decrease in total phenols with a significant yield increase only due to MSWC application to the soil (Botelho *et al*., 2022). However, in the present work, no increases in yield were recorded and, thus, no decrease in total phenols was expected.

The wine colour, evaluated using CIELab parameters, showed high levels of clarity; despite being significantly different between pruning treatments, the differences were so small that they are probably not of technological importance. The a* values are significantly different between pruning treatments in 2018 only, showing that MEC wines are less green than MAN ones (Cosme *et al*., 2008). However, the obtained values a relatively low compared to the values reported by other published work (Cosme *et al*., 2008; Antoce *et al.,* 2016; Silva *et al*., 2024), indicating that these wines do not have an intense green colour. The b* values of MEC are significantly lower in 2020, indicating less yellow wines (Cosme *et al*., 2008). The recorded values are similar to those obtained for Muscat Ottonel (Antoce *et al*., 2016), but lower than those obtained for Arinto and Muscat d'Alexandrie (Silva *et al*., 2024). Although some significant differences were recorded, the tasters were not able to detect them in the sensory analysis (Table 5).

The wine chroma was relatively low compared to the results of other studies (Cosme *et al*., 2008), which is typical of wines with low colour intensity. The hue results show that all the wines are close to 90, indicating wines with a predominantly yellow colour (Pissarra *et al*., 2005) and thus corroborating the a* and b* parameter results. MSWC had no significant effects on the CIELab parameters, except for hue in 2020,

when M1 was significantly lower than M0; however, the difference is so small (less than 2 %) that it is not of technical interest.

An analysis of the colour differences between treatments revealed ΔE values which indicate differences in colour in 2018 and 2019 that cannot be distinguished by tasters (Spagna *et al*., 1996), even the experienced ones (Mokrzycki & Tatol, 2011). However, in 2020, the ΔE values showed differences in colour between pruning systems and MSWC treatments (values between 1 and 2) that can be detected only by experienced tasters (Mokrzycki & Tatol, 2011), despite no differences being detected in the sensory analysis (Table 8).

The sensory analysis revealed small differences across treatments, namely in the cat pee and vegetal aromas in 2018, which were more intense in hand pruning. These aromas are important in Sauvignon wines, as they are preferred by a high proportion of consumers (King *et al*., 2011). The cat pee aroma is associated with volatile thiols, which, rather than being affected by grape exposure (Martin *et al*., 2016), seem to be related to vine nitrogen status (Helwi *et al*., 2016). According to Botelho *et al*. (2021a), MEC tendentially reduces vine nitrogen status due to growth-induced dilution; therefore, it can be hypothesised that the cat pee aroma was less evident due to the nitrogen reduction in MEC. However, vegetal aromas are related to methoxypyrazine (King *et al*., 2011). The concentration of this flavour is significantly reduced by grape exposure to sunlight (Martin *et al*., 2016). In 2019, wines from MAN had slightly higher aroma intensity and balance. Botelho *et al*. (2022), working with Syrah, also found slight, but significant, decreases in aroma balance with mechanical pruning. However, despite some differences between pruning systems in terms of olfactory attributes, the tasters did not differentiate the wines in either of the treatments, as highlighted by the general appreciation results. Tasters also found some slight differences in acidity in 2019, with MAN wines being perceived as more acid than MEC; however, the difference is very small (0.06 points) and is not corroborated by laboratorial analysis (Table 4).

MSWC application also led to slight differences in wine aroma, namely in 2019 with the higher MSWC doses leading to fruitier and more balanced wines. Furthermore, in 2019, the application of MSWC led to more bodied wines with higher overall appreciation. These results contrast with those obtained by Botelho *et al*. (2022), who found no significant differences in fruity aroma, a tendency for less balanced aromas, less body and lower overall appreciation. However, in the referred work, the MSWC treatments produced significantly higher yields, which probably affected the results.

CONCLUSIONS

The effect of the interaction between mechanical pruning and soil amendment with MSWC on vine performance and wine quality was studied over 4 years. The results show a significant increase in yield with mechanical pruning, as well as an increase in sugar content, thus indicating higher canopy efficiency. The results of the overall analysis showed that the pruning system did not affect wine characteristics or quality (classical parameters, colour, phenolic compounds and sensory profile), indicating that this is a viable option for pruning Sauvignon in this *terroir,* which reduces costs and increases vineyard profitability.

The application of MSWC to the soil did not affect yield or its parameters. In the present study the soil amendment with MSWC was accompanied by an application of nitrogen, that may have overshadowed the effect of the MSWC. Although a primary analysis indicates that the application of MSWC to soil may not be a profitable practice, other side effects may be considered to justify it; *i.e.*, the potential increase in soil water-holding capacity resulting from the rise in soil organic matter content (Table S2), which in non-irrigated vineyards may be crucial in the increasingly frequent dry years.

Thus, mechanical pruning is a powerful tool for the sustainable intensification of the vineyard, increasing yield and profitability and having almost no impact on the environment. Despite MSWC not contributing to vineyard profitability in the present study, in certain conditions it may be possible to use it as a tool for increasing vineyard resilience.

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