ITALUS HORTUS

Vol. 31 (2024), Pages 1-10
doi: 10.26353/j.itahort/2024.2.0110

Original Research Paper

Effect of early shoot trimming on canopy architecture and vine performance of Carricante grapevines

Filippo Ferlito[1], Daria Costantino[1], Serena Camuglia[1], Giuseppina Las Casas[1], Lucia Giordano[2], Alberto Palliotti[2], Leonardo Paul Luca[3], Stefano La Malfa[3], Alessio Giuffrida[3], Lorenzo Rapisarda[3], Alessandra Gentile[3] and Elisabetta Nicolosi[3*]

[1] Council of Agricultural Research and Economics, Research Centre for Olive, Fruit and Citrus Crops, Acireale (CT), Italy
[2] Department of Agricultural, Food and Environmental Sciences, University of Perugia, Italy
[3] Department of Agriculture, Food and Environment, University of Catania, Italy
[*] Corresponding author: elisabetta.nicolosi@unict.it

Received: 12 September 2024; Accepted: 28 November 2024; Available online: 30 November 2024

Abstract: Morpho-physiological changes, excessive sugar accumulation, low acidity and color, and atypical flavors have been well documented worldwide as a consequence of global warming. These upheavals suggest a re-think of viticulture models and/or management strategies. This study focused on early shoot trimming to evaluate how changes in canopy architecture can influence its functionality and grape qualitative-quantitative traits. The experiment was carried out in 2023 in a 12-year-old vineyard on Etna Mount (Sicily island) on the white grape variety 'Carricante'. At the BBCH73 stage (berries groat-sized), all shoots on 180 vines were trimmed at the height of the node above the last bunch (TR), whereas the other 180 vines were subjected to late shoot trimming during the last week of August (CT). The early trimming removed 61% of the total leaf area and did not cause any berry drop. The vine performances were influenced by high temperatures in summer, with peaks of over 46 °C, which were responsible for the premature senescence of basal leaves from primary shoots and the lack of development of laterals in CT vines. The TR determined a change in vine architecture, characterized by a reduced vigour and canopy height and an increase in the leaf area (+34%), thanks to lateral shoot development, resulting in the most dense canopy. In the TR vines, the yield and their components were unchanged compared to CT vines, whereas a reduction in sugar (21.6 *vs.* 23.1 °Brix) and an increase in polyphenols (+20%) were found.

Keywords: shoot topping, grape composition, gas exchange, viticulture, primary and lateral leaves.

1. Introduction

Due to its genetic and phenotypic diversity, the grapevine (*Vitis vinifera* L.) is one of the oldest and most widely cultivated tree crops globally. In 2022, the International Organisation of Vine and Wine declared that the globally cultivated vineyard area was 7.3 million hectares (Mha), producing approximately 260 million hectolitres (MhL) of wine. The projection of world wine production is estimated to be a mid-range of 244 MhL (-7%). This volume represents the smallest since 1961, at 214 MhL, surpassing the historically low production volume of the 2017 season, which was 248 MhL. This unfavourable scenario can be attributed to a significant decline in major wine-producing countries in both hemispheres. Those in the Northern Hemisphere, such as Italy, where a reduction of 12% (43.9 MhL) was recorded in 2023 (OIV, 2023), were the most affected by the adverse climatic conditions during the growing season. The productive decline is due to both abiotic and biotic stress. In particular, extreme events such as floods, hailstorms, prolonged drought, and strong winds have become widespread and frequent. In several cases, late rains and prolonged periods of high relative humidity have been the cause of an increase in fungal disease, especially in the Italian southern regions (OIV, 2023). The phenomenon fits into the general climate change scenario, strongly impacting vegetative and reproductive vine behaviour. The main indicators of climate change are the rise in air temperatures and CO_2 concentrations, and a marked reduction in precipitation, which leads to frequent water deficit events (Arrizabalaga-Arriazu et al., 2020; Martínez-Lüscher et al., 2016; Sodini et al., 2023). These conditions are responsible for physiological alterations, negatively affecting crop development and yield (Petrie and Clingeleffer, 2008) and reducing the length of the phenological phases, thus determining an advance in grape ripening (Jones et al., 2005). Moreover, a decrease in anthocyanins, fatty and organic acids and aroma compounds was also reported (Mori et al., 2007; Lecourieux et al., 2017). These factors cause the production of musts with elevated potential alcohol content, higher pH, and reduced acidity and color (Iorizzo et al., 2023). Furthermore, this trend is responsible for reducing the quantity and complexity of aromas, with consequent modification of the wine traits. Therefore, climate change adaptation strategies are mandatory to support the production of high-quality wines and preserve their distinctive characteristics based on their origin (Van Leeuwen and Darriet, 2016). These may concern the grape variety, the growing region, and the agronomic techniques (Sotès, 2018). Under rising temperatures, considering that in many traditional areas it is not advisable to modify the genetic component (Bennici et al., 2018), it is important to adapt soil and vine management (Ferlito et al., 2018).

In this context, vineyard canopy management, especially the summer pruning techniques tailored to this specific scenario, could serve as a resource to increase viticulture resilience to climate change challenges. In the past, the summer pruning techniques were used to improve the bunch exposition to the sun or to prevent grape disease (i.e. leaf removal and late topping), but nowadays, they could improve vine resilience to extreme climatic conditions (Ferlito et al., 2020; Nicolosi et al., 2021). In particular, the shoot trimming strategy could be revised as a useful tool for changing the canopy architecture when applied early in the season with the aim of: i) improving the lateral leaves growth and efficiency; ii) modifying the source/sink balance and consequently the technological grape characteristics, delaying berry ripening; iii) ensuring the control of fungi infection in the mid-late season. To evaluate whether the modification of the architecture and arrangement of the canopy affect its functionality, early shoot trimming was examined as a strategy to limit damage due to ongoing climate changes.

2. Materials and Methods

2.1. Site descriptions, plant material and vine canopy management

The research was carried out in a rainfed vineyard located on the Etna Mount (Sicily Island, South Italy, lat. 37°41'19.95"N; long. 15° 9'23.93"E; alt. 252 m a.s.l., eastern slope) on 12-years-old vines of the white grape cultivar 'Carricante', grafted onto 140 Ru. rootstock, in rows orientated E-W, spaced 2.5 m × 1.2 m (3.333 vines/ha). Vines were trained using a vertical-shoot positioned, spur-pruned permanent cordon at 0.7 m from the soil and the top of the canopy at approximately 1.90 m. Vines were spur-pruned from six to ten nodes per vine (two nodes per spur and three to five spurs per vine). A simple canopy management treatment was arranged to conduct the trial over a preliminary first season, from 24 May 2023 to 15 February 2024. The experimental design was completely randomized with three independent experimental units (blocks) and two treatments per experimental unit, each consisting of 3 rows containing 60 vines each. All measurements were made on nine uniform vines per treatment selected in the central part of each block. Two canopy management treatments were compared: (i) early trimming (TR) and (ii) conventional trimming (CT, Control). In the TR treatment, shoots were manually trimmed at the node's height above the last bunch at the BBCH 73 stage (berries groat-sized, bunches begin to hang) (Figure 1). The CT vines were trimmed during the last week of August according to the common cultural practices in the area.

2.2. Climatic and soil characteristics

A weather station located near the experimental vineyard provided monthly minimum, mean and maximum air temperatures and rainfall data. According to the USDA scheme, the soil is classified as loamy-sandy and sub-acid.

Figure 1. Vines subjected to the early shoot trimming (BBCH 73).

2.3. Vegetative growth monitoring

The area of removed leaves from primary and lateral shoots was determined using a leaf area meter (model LI-3100; Licor, Inc., Lincoln, NE). The remaining leaf area per vine was estimated by multiplying the number of all primary and lateral leaves by the relative average leaf area previously calculated, sampling 25 basal, 25 medial and 25 apical leaves and measuring their leaf area. At harvest, on 25 September, the same measurements were repeated in both treatments to evaluate the leaf area per vine and the percentages of leaf area from primary and lateral shoots. In CT vines, no significant regrowth occurred after the standard shoot trimming made at the end of August.

2.4. Physiological measurements

Base physiological parameters were measured with a portable infrared gas analyzer IRGA (Leaf Chamber Analyzer-ADC LCA4 Bio Scientific Ltd., Rickmansworth, England) using three leaves per treatment per experimental unit (a total of 9 leaves) per measurement date. Midday leaf water potential was measured with a Scholander pressure chamber (Soil Moisture Equipment Corp., Sta. Barbara, CA, USA) using nine leaves (three leaves per experimental unit). All measurements were carried out monthly from 15 June to 15 September between 12:00 a.m. and 1:30 p.m. Data were collected on fully exposed basal primary leaves until their full senescence (first two data of measurements) both for TR and CT; then we used fully exposed lateral leaves on mid-shoots both for TR and CT treatments and fully exposed primary leaves on mid-shoots on CT treatment**.**

2.5. Yield and berry characteristics

Yield per vine was measured and grape composition analysed at harvest (25 September). Bunches were collected from nine vines per treatment on each block to determine fruit yield. A sample of five bunches per experimental unit (15 bunches per treatment) was used to determine the bunch weight and the number and weight of berries. A three replicates sample of 100-berry per experimental unit, were crushed with a manual press and free-run juice utilized to determine total soluble solids (TSS), must pH, and titratable acidity (TA), using an automatic titrator as described by Nicolosi et al. (2016). Total polyphenol was determined using the Folin-Ciocalteau reagent assay and expressed as mg/kg of grapes (Nicolosi et al., 2021).

2.6. Statistical analysis

Analysis of variance (randomized complete block design ANOVA) was performed with Jamovi 1.2 statistical software (Jamovi, 2020). A post-hoc analysis based on Tukey HSD test (Tukey honest significant differences) was performed at significance levels (p-value) of 0.05.

3. Results

3.1 Environmental conditions

In 2023, the maximum and minimum air temperatures showed similar trends compared to the 2012-2022 decade time series, except for July 2023, which was higher for both parameters (Figure 2). In particular, in July, the maximum temperature exceeded 46 °C. From April to September, the total annual rainfall in 2023 was equivalent to 161 mm compared to 177 mm of the 2012-2022 decade. In general, the amount of rainfall in July and August was very low.

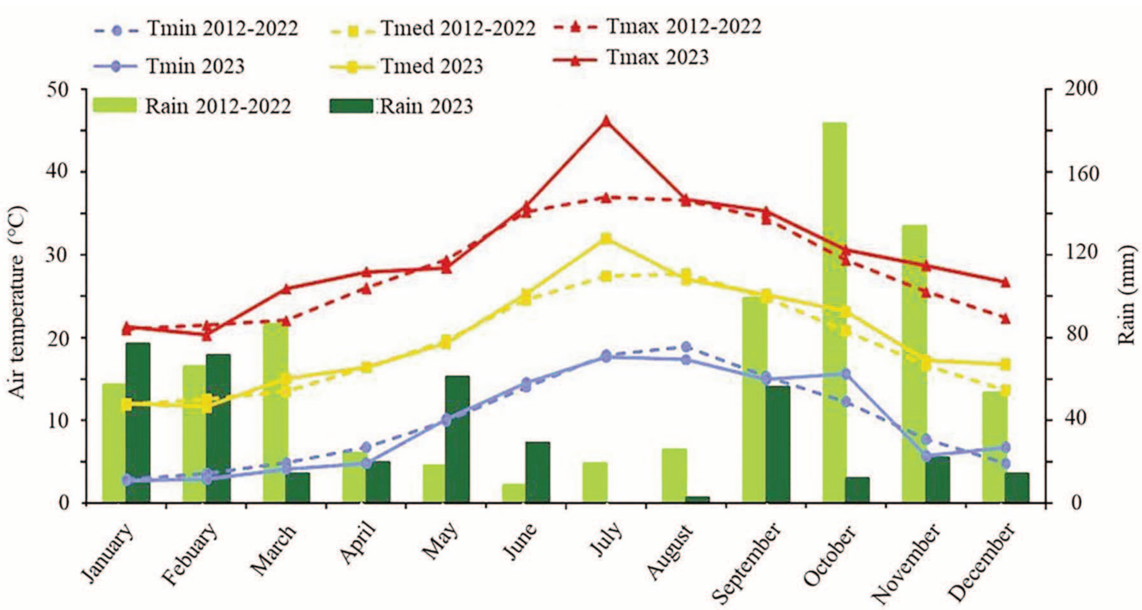

Figure 2. Monthly minimum, mean, and maximum air temperatures and rainfall measured at the experimental field in the last decade (2012 - 2022) and during 2023.

3.2. Growth activity

On the trimming date (BBCH73), the total leaf area per vine (TLA) was represented basically by primary leaves located on main shoots (about 4,821 cm^2), whereas the leaf area provided by laterals was 357 cm^2 per vine (Table 1 and Figure 1). The percentage of the removed leaf area from vines was approximately 61%, 2,938 cm^2 from main shoots and 218 cm^2 from laterals. At harvest, the TR vines showed a higher TLA (+34%) compared to CT. For the latter, the entire surface was made up of primary leaves; in fact, no lateral growth was observed under the trial conditions. On the contrary, for the TR vine, the entire final surface was made up of lateral leaves, as the retained basal primary leaves were fully senescent and dropped in mid-July. In winter the pruning wood from the CT vines was 1.6 kg (94% from primary shoots and 6% from lateral ones) while, approximately 0.64 kg was cut from each

TR vine, 55% from primary shoots and 45% from lateral shoots (Figure 3).

Table 1. Leaf area characteristics of vines at the trimming time and at harvest.

Shoot trimming (BBCH73)						Grape harvest (BBCH91)					
Before trimming			After trimming			Trimmed vines			Control vines		
Primary shoot leaf area (%)	Lateral shoot leaf area (%)	Total leaf area/vine (cm^2)	Primary shoot leaf area (%)	Lateral shoot leaf area (%)	Total leaf area/vine (cm^2)	Primary shoot leaf area (%)	Lateral shoot leaf area (%)	Total leaf area/vine (cm^2)	Primary shoot leaf area (%)	Lateral shoot leaf area (%)	Total leaf area/vine (cm^2)
93	7	5.179 ± 684	95	5	2.002 ± 383	0.0	100	13.157 ± 3214	100	0.0	9.804 ± 1,416

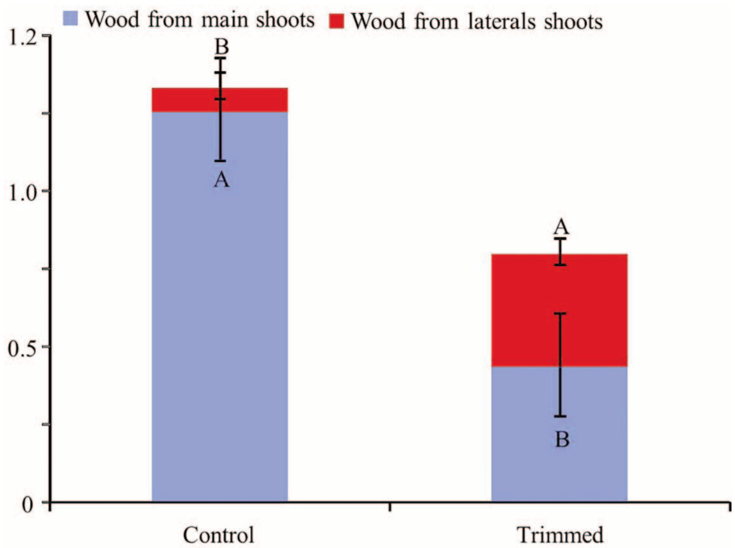

Figure 3. Winter pruning weight from primary and lateral shoots. Mean values for each treatment indicated by different letters are significantly different ($p \leq 0.001$, based on Tukey's HSD). Bars indicate one standard deviation.

3.3. Physiological behavior

On the first measurement (mid-June), the photosynthetic rate of median and basal primary leaves was significantly higher, in both CT and TR vines, while in mid-July this behavior was confirmed only by the median primary leaves in the CT vines. A strong decline was assessed mainly in basal primary leaf types (Figure 4a) that became senescent in both treatments. Therefore, from mid-July onwards, the physiological behaviour of the vines was measured on both primary and lateral leaves for the CT vines but only on the lateral leaves for the TR vines. As regards the latter vines, no significant differences in the photosynthetic activity were registered between the two typologies of leaves on each measurement date (Figure 4d).

As regards the transpiration, only in mid-July the basal primary leaves and the median primary leaves of the CT and TR vines, respectively, registered a significant lower value (Figure 4c,d). Concerning the stomatal conductance, the median primary leaves of the CT vines maintained a significantly better performance compared to the others, while the lateral leaves of the TR vines showed a significantly reduction in stomatal conductance later, in mid-August, (Figure 4e,f). The water potential of the median primary leaves of the CT vines, highlighted the highest negative values in mid-July (Figure 5a). In mid-June and mid-August, the lateral leaves from RT vines showed the most negative leaf water potential values, up to -1.65 MPa (Figure 5b). This behavior was probably linked to a higher leaf area from the laterals in TR vines, which are more sensitive to high irradiance and temperature compared to CT leaves. In particular, July was the hottest and most stressful month, reaching a maximum monthly temperature of 46.2 °C (+9.3 °C compared to the previous 10 years) (Figure 2).

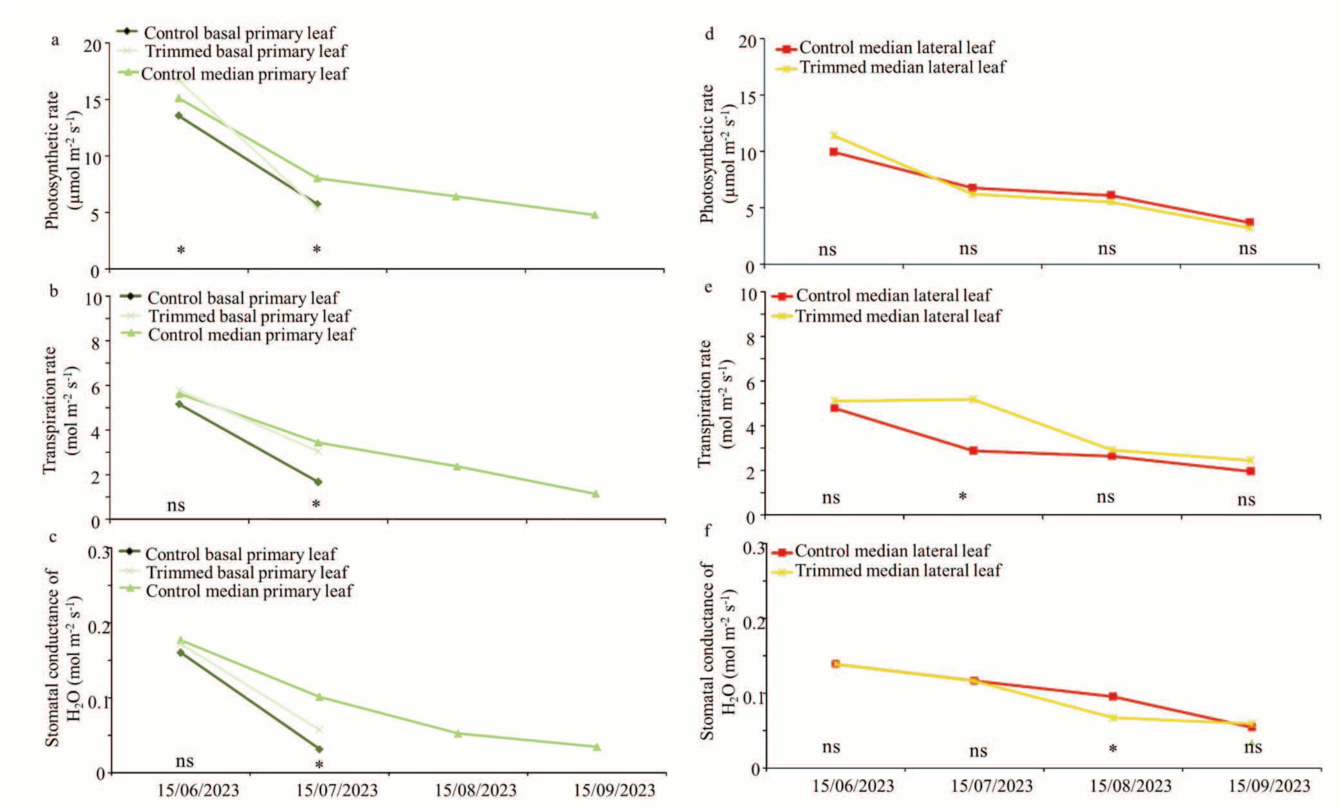

Figure 4. Physiological parameters measured on primary (a,c,e) and lateral leaves (b,d,f) during the growing season. The mean values for each data are reported (*= significantly different at p≤0.05, n.s. = not significant, based on Tukey's HSD test).

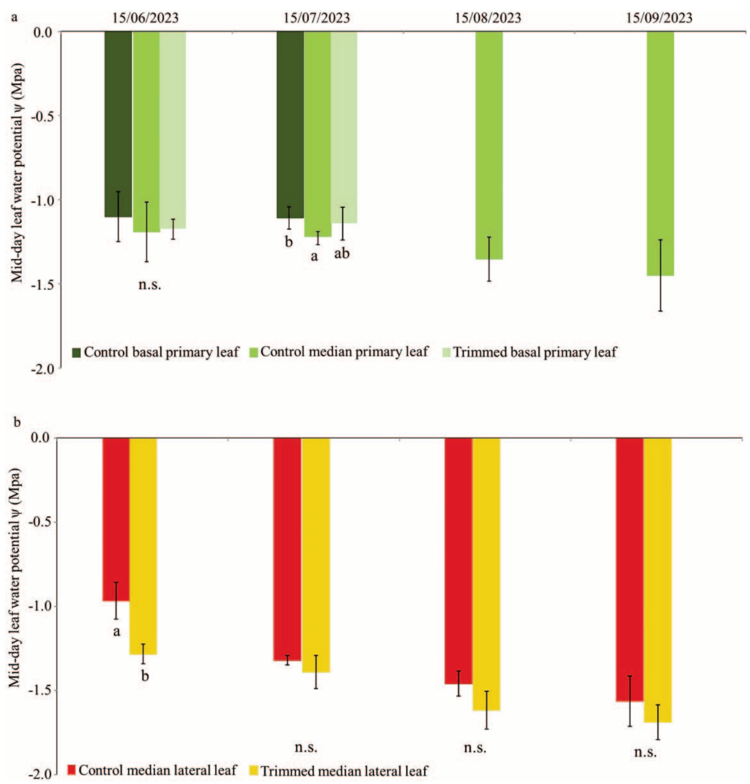

Figure 5. Midday leaf water potential measured on primary (a) and lateral (b) leaves during the season. Mean values indicated by different letters are significantly different ($p \leq 0.05$, n.s. not significant, based on Tukey's HSD). Bars indicate one standard deviation.

3.4. Yield and grape quality

No significant difference was found between CT and TR vines regarding fruit yield per vine, the number of bunches per vine, the bunch weight, the berry weight and number of berries per bunch, and the rachis weight (Table 2).

Table 2. Influence of early trimming on yield and its components. Mean values for each parameter indicated by different letters are significantly different ($p \leq 0.05$), based on Tukey's HSD.

Parameters	Control	Trimmed
Yield/vine (kg)	1.67±0.57n.s.	1.55±0.30n.s.
Bunch/vine (n°)	11.78±3.99n.s.	9.89±1.90n.s.
Bunch weight (g)	143.09±37.17n.s.	156.51±90.23n.s.
Berry weight (g)	2.26±0.42n.s.	2.13±0.30n.s.
Berries/bunch (n.)	64.11±21.32n.s.	75.0±28.80ns.
Rachis weight	13.50±1.47n.s.	17.17±3.57n.s.
Total soluble solids (°Brix)	23.09±0.22a	21.64±0.50b
Titratable acidity (g/L)	3.62±0.66n.s.	3.80±0.36n.s.
Must pH	3.58±0.16n.s.	3.45±1.11n.s.
Total polyphenols (mg/kg fw)	286.79±12.90b	341,98±26.97a

The must qualitative traits highlighted a significant decrease in total soluble solids (about -1.5 °Brix) and an increase in total polyphenols (+19%) in trimmed vines compared to control.

4. Discussion

In the context of intense and prolonged global warming, such as that experienced in southern Italy, including the island of Sicily, it is important to prevent the overheating of grape bunches and leaves. One way to do this is by implementing a canopy management strategy that involves opening up or expanding the canopy during the summer. However, the effects of canopy manipulation, like shoot trimming, are heavily influenced by the unpredictable weather that occurs after the trimming, especially if it is done early in the season. The rainfall and air temperature following the trimming can impact the vine's lateral regrowth, physiological behavior, and overall productivity (Poni et al. 2014).

Despite low rainfall from May to September 2023, only 161 mm, the shoot trimming applied just after fruit-set at the height of the node above the last bunches initiated a good development of the lateral shoots with 1.3 m^2 of leaves per vines, while all the leaves from main shoot fell early. This behaviour could be attributed to the use of limited water for laterals growth rather than sustaining primary leaves in high temperatures. Other cultivars showed the same behaviour. Under strong summer stresses, 'Sangiovese' vines preferred to maintain the young leaves, including those from lateral shoots, in good physiological efficiency. In contrast, the older leaves from primary shoots were subjected to photoinhibition with chlorosis and necrosis (Palliotti et al., 2014). In control vines, the lack of lateral development may be due to the limited capability of 'Carricante' to develop secondary shoots (genetic predisposition), which was also exacerbated by limited rainfall and high temperatures.

The early shoot trimming did not affect the yield per vine as it was done after the fruit-set was completed. However, Vasconcelos and Castagnoli (2000) reported an increase in fruit set when trimming was done at the pre-bloom stage.

It is noteworthy that the TR vines showed a lower soluble solids accumulation in the must (-1.5 °Brix compared to CT vines) despite having the same yield per vine and a higher leaf area (+0.33 m^2/vine). This resulted in a leaf area/yield ratio of 0.58 m^2/kg for the CT vines and 0.84 m^2/kg for the TR vines. The decrease in soluble solids accumulation in the TR vines might be due to the lower photosynthetic rate of the lateral leaves developed in shade conditions.

The TR performed at the berries groat-sized changed vine canopy structure. This resulted in shorter and less vigorous growth with an increase in the final leaf area due to lateral shoot development, creating a dense canopy with more shaded interior leaves. Palliotti et al. (2000) reported a 50-55% reduction in photosynthetic rate in lateral shade-leaves compared to lateral sun-leaves in two different grapevine cultivars. In TR vines the yield/pruning ratio showed a higher Ravaz index compared to CT vines, specifically 2.40 versus 1.60. This indicates a better balance between the source (leaves) and sink (fruits) for the 'Carricante' grape cultivar, which is known for its strong vegetative growth, high basal fertility, and small bunches.

5. Conclusions

The obtained results during 2023 must be considered preliminary and were certainly influenced by low rainfall and high temperatures registered in mid-summer, with peaks of over 46 °C, which were responsible for premature senescence of basal leaves from primary shoots in both treatments and lack of lateral shoots development in CT vines. The TR performed just after the berry set determined a significant change in the canopy architecture, characterized by a reduction in annual pruning weight and height of the canopy and an increase in the final leaf area (+34%), thanks to lateral shoot development, resulting in a most dense canopy. The physiological performance of the TR was similar to that of the CT vines, but in the TR vines, this performance from mid-July to grape harvest was guaranteed only by the lateral leaves. The yield in the TR vines was unchanged in comparison to CT vines, whereas the TR treatment influenced the qualitative traits by reducing the must soluble sugar content and improving the total amount of polyphenols. Finally, in comparison to late shoot trimming (last week of August, which is the common date in this area) the early shoot trimming, applied just after fruit-set, could represent a useful tool to reduce excessive accumulation of sugar in the grapes and consequently high alcohol content in the wines. In hot and dry environments, this technique can also be used as a tool to delay the ripening processes, improving the phenolic maturity and polymerization, which is extremely important above all for the red grape varieties. Moreover, this technique is cost effective because it does not involve an additional operation, but it is the same standard shoot trimming, only executed 12-13 weeks before. Additionally, it is easy to apply because it does not require particular skills.

Funding: This research received no external funding.

Acknowledgements: The authors want to thank the farm Villa Fago for hosting the trial and for assistance in the field.

Conflicts of Interest: The authors declare no conflict of interest.

References

Arrizabalaga-Arriazu, M., Gomès, E., Morales, F., Irigoyen, J.J., Pascual, I. and Hilbert, G. (2020) 'High temperature and elevated carbon dioxide modify berry composition of different clones of grapevine (*Vitis vinifera* L.) cv. Tempranillo', *Frontiers Plant Science,* 11, 1888. doi: 10.3389/fpls.2020.603687

Bennici, S., Las Casas, G., Distefano, G., Di Guardo, M., Continella, A., Ferlito, F., Gentile, A. and La Malfa, S. (2018) 'Elucidating the contribution of wild related species on autochthonous pear germplasm: A case study from Mount Etna', *PloSOne,* 13(6), e0198512. doi: 10.1371/journal.pone.0198512

Ferlito, F., Allegra, M., Torrisi, B., Pappalardo, H., Gentile, A., La Malfa, S., Continella, A., Stagno, F. and Nicolosi, E. (2020) 'Early defoliation effects on water status, fruit yield and must quality of 'Nerello Mascalese' grapes', *Scientia Agricola,* 77, p.e. 20190025. doi: 10.1590/1678-992x-2019-0025

Ferlito, F., Nicolosi, E., La Malfa, S., Cicala, A. and Gentile, A. (2018) 'First characterization of minor and neglected *Vitis vinifera* L. cultivars from Mount Etna', *Horticultural Science,* 45, pp. 37-46. doi: 10.17221/198/2016-HORTSCI

Iorizzo, M., Sicilia, A., Nicolosi, E., Forino, M., Picariello, L., Lo Piero, A.R., Vitale, A., Monaco, E., Ferlito, F., Succi, M., Tremonte, P., Gambuti, A., Villano, C., Bonfante, A., Aversano, R. and Coppola, R. (2023) 'Investigating the impact of pedoclimatic conditions on the oenological performance of two red cultivars grown throughout southern Italy', *Frontiers Plant Science,* 14, 1250208. doi: 10.3389/fpls.2023.1250208

Jones, G.V., White, M.A., Cooper, O.R. and Storchmann, K. (2005) 'Climate change and global wine quality', *Climate Change,* 73, pp. 319-343. doi: 10.1007/s10584-005-4704-2

Lecourieux, F., Kappel, C., Pieri, P., Charon, J., Pillet, J., Hilbert, G., Renaud, C., Gomès, E., Delrot, S. and Lecourieux, D. (2017) 'Dissecting the biochemical and transcriptomic effects of a locally applied heat treatment on developing Cabernet Sauvignon grape berries', *Frontiers Plant Science,* 8, 53. doi: 10.3389/fpls.2017.00053

Mori, K., Goto-Yamamoto, N., Kitayama, M. and Hashizume, K. (2007) 'Loss of anthocyanins in red-wine grape under high temperature', *Journal Experimental Botany,* 58, pp. 1935-1945. doi: 10.1093/jxb/erm055

Nicolosi, E., Iovino, V., Distefano, G., Di Guardo, M., La Malfa, S., Gentile, A., Palliotti, A., Las Casas, G. and Ferlito, F. (2021) 'Mid-term effects of conservative soil management and fruit-zone early leaf removal treatments on the performance of Nerello Mascalese (Vitis vinifera L.) grapes on Mount Etna (Southern Italy)', *Agronomy,* 11(6), 070. doi: 10.3390/agronomy11061070

Nicolosi E., Ferlito F., Allegra M., Cicala A., Trovato F. and La Malfa, S. (2016) 'Influences of aspect and tillage on two wine grape cultivars on Mount Etna', *New Zealand Journal of Crop and Horticultural Science,* 44 (2), pp. 83-102. doi: 10.1080/01140671.2016.1147472

OIV (2023) 'World Wine Production Outlook - OIV First Estimates 07.11.2023', International Organization of Vine and Wine.

Palliotti, A., Cartechini, A. and Ferrante, F. (2000) 'Morpho-structural and physiological characteristics of primary and lateral shoot leaves of Cabernet Franc and Trebbiano Toscano grapevine under two irradiance regimes', *American Journal of Enology and Viticulture,* 51(2), pp. 122-130. doi: 10.5344/ajev.2000.51.2.122

Palliotti, A., Tombesi, S., Frioni, T., Famiani, F., Silvestroni, O., Zamboni, M. and Poni, S. (2014) 'Morpho-structural and physiological response of container-grown Sangiovese and Montepulciano cvv. (Vitis vinifera) to re-watering after a pre-veraison limiting water deficit', *Functional Plant Biology,* 41 (6), pp. 634-647. doi: 10.1071/FP13271

Petrie, P.R., Clingeleffer, P.R. (2008) 'Effects of temperature and light (before and after budburst) on inflorescence morphology and flower number of Chardonnay grapevines (Vitis vinifera L.)', *Australian Journal of Grape and Wine Research,* 11, pp. 59-65. doi: 10.1111/j.1755-0238.2005.tb00279.x

Poni, S., Zamboni, M., Vercesi, A., Garavani A. and Gatti, M. (2014) 'Effects of early shoot trimming of varying severity on single high-wire trellised Pinot noir grapevines', *American Journal of Enology and Viticulture,* 65(4), pp. 493-498. doi: 10.5344/ajev.2014.14037

Sodini, M., Callesen, T., Canton, M., Tezza, L., Campos, F.B., Zanotelli, D., Tarolli, P., Sivilotti, P., Pitacco, A. and Tagliavini, M. (2023) 'Major threats caused by climate change to grapevine', *Italus Hortus*, 30(2), pp.1-24. doi: 10.26353/j.itahort/2023.2.0124

Sotés, V. (2018) 'Impacto y adaptación al cambio climático en España. In El sector vitivinícola frente al desafío del cambio climático', 1st ed. Cajamar caja Rural, Spain, I, pp. 45-64.

The jamovi project. Jamovi. (Version 1.2) [Computer Software] (2020) Retrieved from https://www.jamovi.org

Van Leeuwen, C. and Darriet, P. (2016) 'The impact of climate change on viticulture and wine quality',

Journal Wine Economy, 11(1), pp. 150-167. doi: 10.1017/jwe.2015.21
Vasconcelos, M.C., Castagnoli S. (2000) 'The effect of pre-bloom trimming on fruit set and berry development in grapevines', *Viticulture & Enology,* 21(4), pp. 334-342.